- Goal → Input image with haze ⟼ image without haze

- Technique Used → Image Prior (Dark channel prior)

  ↓

  A statiste of haze free images.

Coloured images → {R,G,B} → 3 colour chanels

Observations →

1) Most local patches in 'outdoor' haze-free images (↗ except sky) contain some 'dark pixels' in atleast one colour channel.

   ↓ pixels with very low intensity values

   Dark Channel Prior. (Prior knowledge / statistic regarding haze-free images.)

2) Images of outdoor scenes are degraded by the presence of turbidity in the atmosphere. Haze is a phenomena caused by absorption and scattering of light by the turbid medium present in the atmosphere.

   Effects on the irradiance recieved by the camera →

   a) attenuation along the line of sight.
   b) Incoming light is blended with 'airlight'.

      ↓ Ambient light reflected/scattered into the line of sight by atmospheric particles.

- Benifits of Haze Removal →
  1) Computational photography.
  2) Computer vision →
     a) Performance improvement due to reduction in biases and low contrast scene radiance.

b) Haze-removal provides useful depth information.

- Challenges in Haze Removal →

  Haze is dependent on unknown 'depth'.

  For a single image, the problem is under-constrained.

- State of the Art in Single Image Haze Removal (2011) →

  Use of stronger priors (or) assumptions.

  a) Haze-free images tend to have higher contrast as compared to their hazy counterparts.

  b) The transmission of light and the surface shading are 'locally' uncorrelated.

  c) Proposed in the paper → Dark channel prior.

- Explanation of Image Dehazing Using Dark Channel Prior →

  In a hazy image, the intensity of the dark pixels is contributed by the airlight. We can estimate the haze transmission by using these dark pixels.

  We Use → 1) A haze imaging model

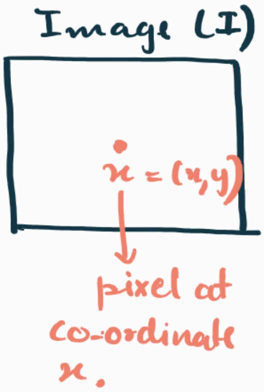
  2) Haze Removal Using Dark Channel Prior

  We obtain a high quality haze-free image and a good depth map.

  Limitations → Might be invalid when the scene object is similar to the airlight.

1) Haze Imaging Model →

Consider an image I s.t. intensity of pixel at co-ordinate x is $I(x)$. Let the actual scene radiance of the scene captured by pixel 'x' is given by $J(x)$. $t(x)$ is the medium transmission along the line of sight of pixel 'x' and A is the atmospheric light. Then,



medium transmission

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

$I(x)$ → Observed intensity

$J(x)$ → Scene radiance

A → Global atmospheric light

medium Transmission $t(x)$ → fraction of light that reahes the camera and is not scattered by the medium.

Direct Attenuation $J(x)t(x)$ → Discribes the decay of the scene radiance in the medium.

Airlight $A(1-t(x))$ → The airlight is the effect of the previously scattered light. It leads to the shift in the scene colours.

For a homogeneous medium → $t(x) = e^{-\beta d(x)}$

where β is the scattering coeff. and $d(x)$ is the scene depth.

Goal of Haze Removal → To recover J, A and t from I.

From eqn. (1), we observe that $I(x)$, $J(x)$ and A must be coplanar in the space spanned by $\{r, g, b\}$. Therefore

$$I(x) - A = (J(x) - A)\, t(x)$$

$$\Rightarrow t(x) = \frac{\| A - I(x) \|}{\| A - J(x) \|}$$

$\therefore$ $\forall$ colour channels, $c \in \{r, g, b\}$ → $t(x) = \dfrac{A^c - I^c(x)}{A^c - J^c(x)}$

Dark Channel Prior →

For an arbitrary image 'J', it's dark channel is given by

$$J^{dark}(x) = \underbrace{\min_{y \in \Omega(x)}}_{\text{Local patch centered at pixel 'x'}} \left(\min_{c \in \{r,g,b\}} J^c(y) \right)$$

From the concept of dark channel, we observe that for haze-free outdoor images,

$$\underbrace{J^{dark}(x) \rightarrow 0}_{\text{Dark Channel Prior}}$$

Low intensity of dark channel is mainly caused by a) Shadows. b) Colourful objects/surfaces.
c) Dark objects.

Natural images tend to have atleast one of the above three (except sky).

2) Haze Removal Using Dark Channel Prior →

Estimating Atmospheric Light (A) →

Going patch by patch, we create a dark channel for each patch in the image. Combining the dark channels of each patch, we get the complete dark channel of the image.

From the above obtained dark channel, we choose 0.1% of the brightest pixels. These pixels are usually the most haze-opaque (highest density of haze). Out of these pixels, the one with the highest intensity in the input image is chosen as the atm. light.

Estimating Transmission →

Assuming the atmospheric light A is known, we get,

$$\frac{I^c(x)}{A^c} = t(x)\frac{J^c(x)}{A^c} + (1-t(x))$$

Assuming that the transmission in the local path $\Omega(x)$ is constant (denoted by $\tilde{t}(x)$), we calculate the dark channel on both sides,

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

But, from our prior, $J^{dark}(x) \to 0$ since the scene radiance is a haze-free image. Therefore,

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

For sky regions $I^c(y) \approx A^c$ so $\tilde{t}(x) \to 0$ which is as expected.

Humans percieve depth due to the presend of haee → aerial perspective.

To make the image feel natural, we keep

a small amount of haze for distant objs.

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

($0 < \omega \leq 1$ is a const. parameter.)

↳ taken as 0.95 in the paper.

Some halos and block artifacts may be present in the de-hazed image using this method. A soft matting method is used to refine the transmission map.

Soft Matting →

Using the matting Laplacian matrix L defined as follows → Consider colours in window w_k,

$$L_{ij} = \sum_{k \mid i,j \in w_k} \left(\delta_{ij} - \frac{1}{|w_k|} \left(1 + (I_i - \mu_k)^T \left(\Sigma_k + \frac{\varepsilon}{|w_k|} I_{3\times3} \right)^{-1} (I_j - \mu_k) \right) \right)$$

pixels i, j in the input image I

we minimize the cost function

$$E(t) = t^T L \tilde{t} + \lambda (t - \tilde{t})^T (t - \tilde{t})$$

to find the optimal value of t. Setting $\lambda \simeq 10^{-4}$, we 'softly' constrain t by $\tilde{t}$. The optimum t is found by solving →

$$(L + \lambda \underline{I}) t = \lambda \tilde{t}$$

↳ identity of size(L).

We then apply bilateral filtering on t to smooth it's small scale textures.

Patch Size → Larger the patch size, better the results but with stronger halo artifacts.

(15x15 used in the paper.)

Recovering Scene Radiance →

Direct attenuation, $J(x)t(x)$ can be very close to 0 when $t(x)$ is close to 0. In such a case, the directly recovered J is prone to noise. There, we restrict $t(x)$ to a lower bound t_0. $J(x)$ is recovered as follows,

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

(A typical value of t_0 is 0.1)

The exposure of $J(x)$ might require to be increased as the images after haze removal tend to look dim.