Haze Removal

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Numerical Imaging Project, February 2021

Introduction

- For images acquired under rainy/foggy conditions, field of view reduced
  - Need to restore them
- Useful for image editing applications

Example

Example

Table of content

Problem Definition

Haze is the reduction of light beams reaching the camera sensor, modelled with:

$$\forall \text{pixel } x,\; I(x) = J(x)t(x) + A(1 - t(x))$$

- Image acquired by the camera: I (known image)
- Light truly emitted by objects: **radiance** J (dehazed image)
- Share of light received by the sensor: **transmission** t
- Color of the haze: **atmospheric light** A

Workflow

- Compute atmospheric light A from I
- Compute transmission $t(x)$ from A and I
- Refine transmission with soft matting or guided filtering
- Compute radiance $J(x)$ from I, A and t
- Correct exposure

Dark Channel Prior

Observation

In most of the non-sky patches of haze-free images, at least one color channel has very low intensity at some pixels.

$$\forall x \notin \text{sky}, \quad \min_{c \in \{r,g,b\}} \min_{y \in \Omega(x)} J^c(y) \approx 0$$

Conversely, haze is characterized by bright pixels: this is the atmospheric light A

Transmission

- **Assumption**: constant transmission over local patches

$$\forall y \in \Omega(x),\ I(y) = J(y)t(x) + A(1 - t(x))$$

- **Optimization**: minimize over the patch and the color channels

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

- **Dark channel prior**: remove null term

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

- Keep a little haze for depth, introducing constant ω

Radiance recovery

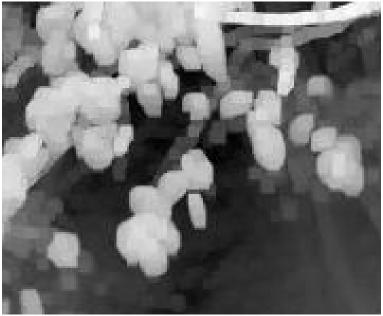
- $I(x) = J(x)t(x) + A(1 - t(x)) \iff I(x) - A = (J(x) - A)t(x)$
- **Threshold** t **on minimal value** t_0 to prevent division by 0:

$$\forall x,\ I(x) - A \approx (J(x) - A)\max(t(x), t_0)$$

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

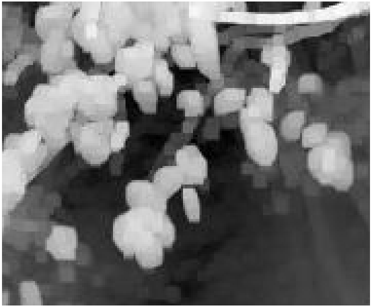
Refining the transmission

- Need a very fine transmission map t to be accurate
- But t depends on patches Ω
- Two improvement methods:
    - Soft matting
    - Guided image filtering

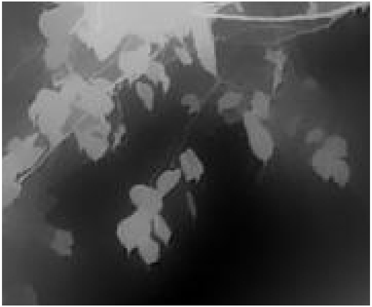


Soft matting

$$t_{\mathrm{sm}} = \mathrm{argmin}_t \underbrace{t^\top L_{\mathrm{Levin}} t}_{\text{alpha-matting}} + \underbrace{\lambda \|t - t_{\mathrm{dc}}\|_2^2}_{\text{data fidelity}}$$



t_{dc} (zoom)



t_{sm} (zoom)

Guided filtering

- Raw transmission map p and guide image I as inputs (I is the RGB image with haze)
- Search for a **linear model** on local windows :

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

- **Convex energy** to optimize:

$$\forall k, E(a_k, b_k) = \sum_{i \in \omega_k} \left[(a_k I_i + b_k - p_i)^2 + \epsilon a_k^2 \right]$$

- Optimization gives formulas for a_k and b_k, then average over windows to obtain q_i
- Very fast algorithm

Fast Guided Filter

- Reuse the guided filtering but with downscaled images, before reupscaling the resulting parameters a and b

$$(I, p) \xrightarrow[\text{factor } s]{\text{Downscale}} (I', p') \xrightarrow[\text{Compute linear parameters}]{\text{Guided filtering}} (\overline{a'}, \overline{b'})$$

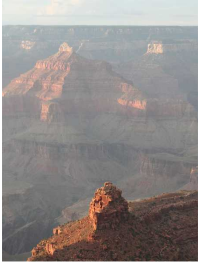
$$(\overline{a'}, \overline{b'}) \xrightarrow[\text{factor } s]{\text{Upscale}} (\overline{a}, \overline{b}) \xrightarrow[q=\overline{a}^T I+\overline{b}]{\text{End of guided filtering}} q$$

- Very similar results
- Faster algorithm (about 10 times faster than guided filtering)

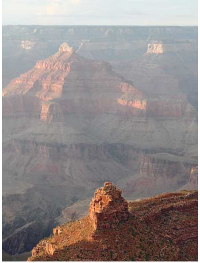
Runtime

Matting method	None	Soft Matting	Guided Image Filtering	Fast Guided Filter
Computation time (s) Image size: 291x600	0.07	5.5	3.1	0.5
Computation time (s) Image size: 680x1400	0.4	28.3	23.3	0.9
Computation time (s) Image size: 972x2000	0.8	54.4	76.0	1.5

Impact of t_0



Original picture



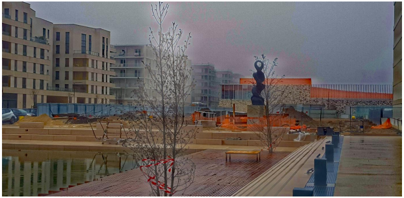
$t_0 = 0.7$

$t_0 = 0.5$

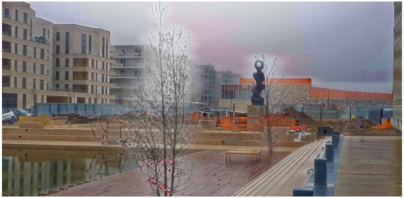
$t_0 = 0.1$

Impact of the patch size

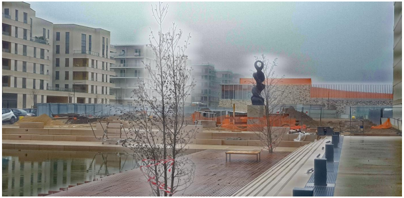
Original picture



Patch size 2



Patch size 5



Patch size 10

Overview of the different methods (1/2)

Original picture

No matting

Soft matting

Guided filtering

Overview of the different methods (2/2)

Original picture

No matting

Soft matting

Guided filtering

Conclusion

- Superiority of the guided filtering over soft matting
- Little fine-tuning necessary
- True to the original image (contrary to ANN that can create details)
- Even faster computation with fast guided filter

- Issue with pictures containing a lot of sky (dark channel prior not respected)