Image Visibility Clarification and Enhancement

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ROBOTICS PROJECT

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Objective

(a) (b)

Figure 1: (a): Haze Image (b): Dehazed Image

Source: *Berman et al.*

Outline

Haze

Haze in Images

- Images of outdoor scenes affected by haze
- Loss of visibility and poor contrast

(a)

(b)

Figure 2: Haze in Images (a): Atmospheric (b): Underwater

Source: *(a): FIDA database (b): Ancuti database*

Dehazing

Dehazing

- Dehazing removes haze in images
- Improves image quality
- Applications in photography
- Useful for computer vision algorithms like object detection, photometric analysis, etc
- Can obtain depth information for scene understanding

Single Image Dehazing Methods

Types

- Filtering based
  1. Screened Poisson Equation for Image Contrast Enhancement [Morel et al., 2013]
- Degradation Model based
  1. Dark Channel Prior [He et al., 2009]
  2. Non-local Dehazing [Berman et al., 2016]

Filtering based Methods

Screened Poisson Contrast Enhancement

- Minimizing the objective function
  $J(u) = \int_\Omega ||\nabla u - \nabla f||^2 dx + \lambda \int_\Omega (u - \bar{u})^2 dx$
- Filtering in frequency domain
- Color balance as pre and post processing steps

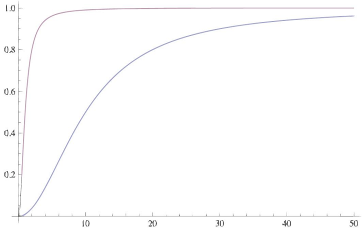


Figure 3: Frequency domain filter

Structure-Texture Decomposition

Structure-Texture Decomposition in SP Enhancement

- Decompose image into structure + texture components [Buades et al., 2011]
- Apply Screened Poisson method on structure component
- Add texture back

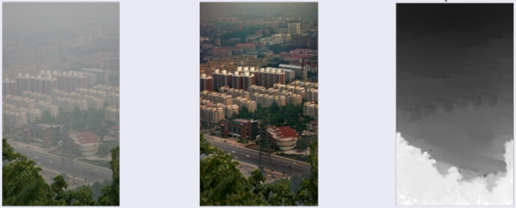
Figure 4: (a): Original (b): Structure (c): Texture

Haze Imaging Model

Physical Degradation Model

Atmospheric Light

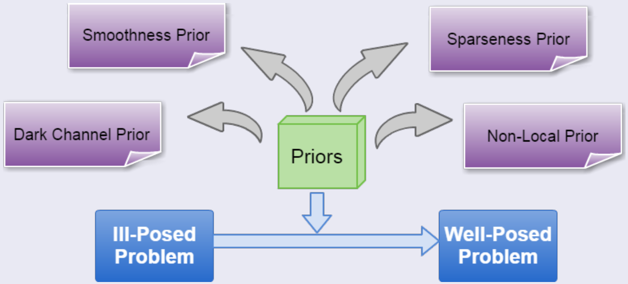
$$I(x)=J(x).t(x)+A.(1-t(x))$$



Hazy Image Scene Radiance Transmission

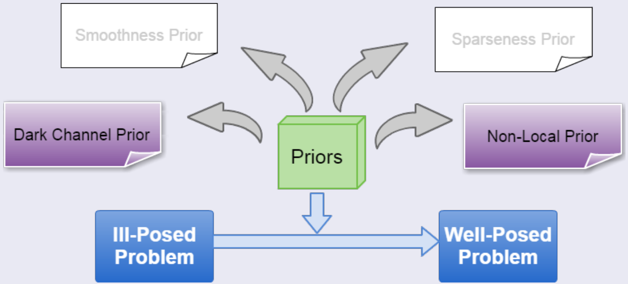
Priors In Computer Vision

Priors In Computer Vision



Priors In Computer Vision

Priors In Computer Vision



Haze Removal using Dark Channel Prior

What is DCP?

- $J^{dark}(x) = \min_{c\in(r,g,b)}\left(\min_{y\in\Omega(x)}(J^c(y))\right) = 0$

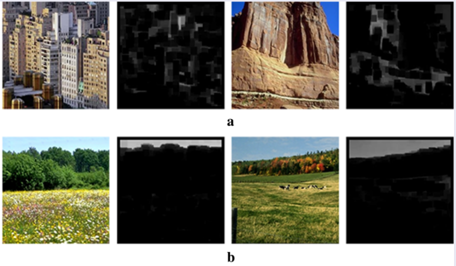


Figure 5: Dark channels of outdoor images [3], where the size of Ω is 15 x 15

Estimation of Airlight

Compute Airlight

- Regions with denser haze have higher intensity in dark channel
- Top 0.1% brightest pixels in the dark channel used

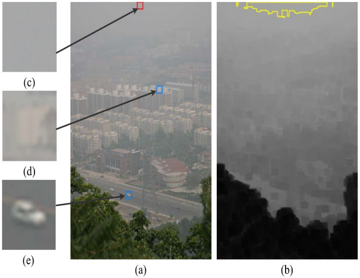


Figure 6: Estimation of Airlight

Estimation of Transmission

Estimation of Transmission

- Normalize: $\frac{I^c}{A^c} = \frac{J^c}{A^c} \times t + (1 - t)$
- Compute Dark Channel: $min_{\Omega}(min_c \frac{I^c}{A^c}) = (min_{\Omega}(min_c \frac{J^c}{A^c})t + (1 - t)$
- $(min_{\Omega}(min_c \frac{J^c}{A^c}) \longrightarrow 0$, using DCP
- $t = 1 - min_{\Omega}(min_c \frac{I^c}{A^c})$

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Transmission Refinement

Transmission Refinement

- Block effects appear in the estimated transmission t(x)
- Laplacian matting is used to refine the transmission

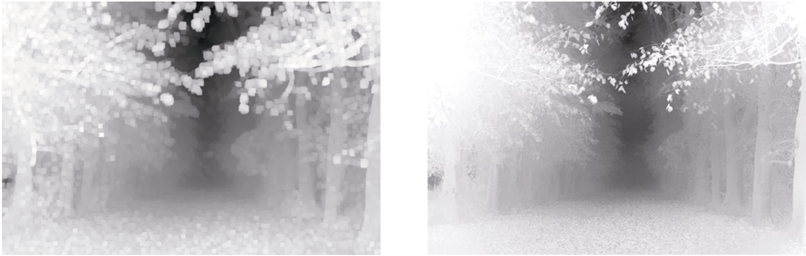


Figure 7: Transmission refinement using soft matting

Guided Image Filter

Guided Image Filter

- Proposed by He et al., ECCV 2010
- Edge-preserving Smoothing Operator
- Linear Translation-Variant Filtering Process

$$q(i) = \sum_j W_{ij}(I)p(j)$$

where W is independent of p

Non-Local Dehazing

Key observations

1. Colors of a haze-free image are well approximated by a few hundred distinct colors forming tight clusters in RGB space
2. Pixels in a given cluster are often non-local
3. In presence of haze, each color cluster becomes a line in the RGB space

Vibot

Non-Local Dehazing

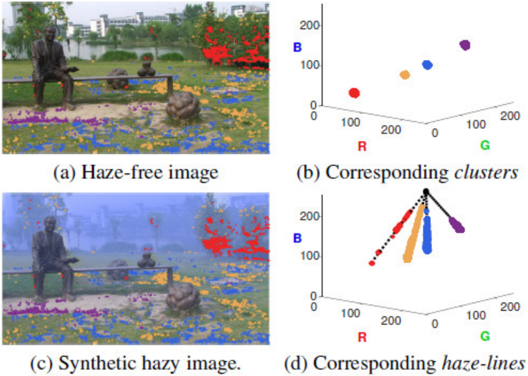


Figure 8: Non-Local Image Dehazing

Non-Local Dehazing

Haze Lines

- Define airlight-centric coordinate system:
  $I_A(x) = I(x) - A$
- Express $I_A(x)$ in spherical coordinates:
  $I_A = [r(x), \theta(x), \phi(x)]$
- Form haze-lines by binning pixels according:
  $[\theta(x), \phi(x)]$

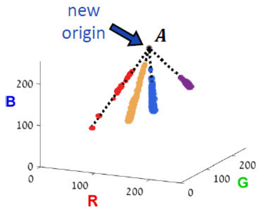


Figure 9: Haze-lines formation

Non-Local Dehazing

Transmission Estimation

- $r(x) = ||I(x) - A|| = t(x).||J(x) - A||,\ 0 \le t(x) \le 1$
- $\hat{r}(x) = \max_{x,y \in H}\{r(y)\}$
- $\tilde{t}(x) = \frac{r(x)}{\hat{r}(x)}$

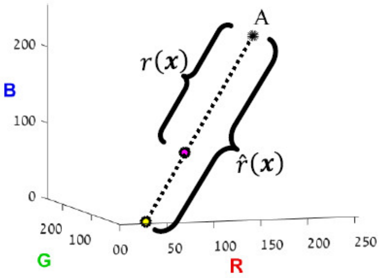


Figure 10: Transmission estimation from haze lines

Image Dehazing Results

Dehazing Results

- Analysis
  - Qualitative
  - Quantitative
- Type
  - Atmospheric
  - Underwater

Image Dehazing Results - Qualitative

Atmoshpheric Dehazing

(a) (b)

Figure 11: (a): Original (b): Screened Poisson Enhanced

Image Dehazing Results - Qualitative

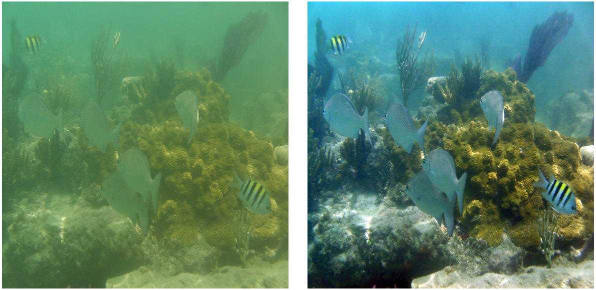
Atmoshpheric Dehazing

(a) (b)

Figure 12: (a): Dark Channel Dehazed (b): Non-local Dehazed

Image Dehazing Results - Qualitative

Underwater Dehazing



(a) (b)

Figure 13: (a): Original (b): Screened Poisson Enhanced

Image Dehazing Results - Qualitative

Underwater Dehazing

(a) (b)

Figure 14: (a): Dark Channel Dehazed (b): Non-local Dehazed

Image Dehazing Results - Quantitative

Quantitative Measures

- Performance is evaluated in terms of the following metric [Qing et al., 2016], here $N = 1$
  - Average gradient (G^c):

$$G^c = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{1}{(R-1)(L-1)} \times \sum_{i=1}^{R-1}\sum_{J=1}^{L-1}\sqrt{\frac{(I_k(i,j)-I_k(i+1,j))^2+(I_k(i,j)-I_k(i,j+1))^2}{2}}\right)$$

Image Dehazing Results - Quantitative

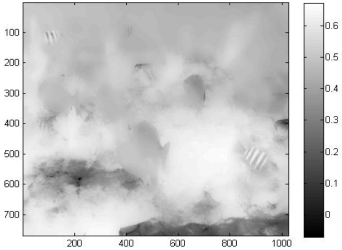
Quantitative Measures - Average Gradient ↑

Image	Channel	Original	SP	DC	NL
Atmospheric	R	6.1461	6.6755	7.5385	**8.2923**
	G	5.8704	6.8873	7.2676	**9.6834**
	B	5.7064	7.0667	7.2183	**9.6253**
Underwater	R	1.4897	3.5708	2.9163	**3.9455**
	G	1.1873	2.9702	2.2838	**3.0295**
	B	1.2907	**4.0904**	2.6644	3.5078

Image Dehazing Results - Transmission Estimation

Depth Map

(a)



(b)

Figure 15: (a): Image (b): Transmission Map from DC Method

Image Dehazing Results - Structure Texture

Structure-Texture + Screened Poisson Enhancement

- Noise $\sigma = 10$

(a)

(b)

Figure 16: (a): SP Enhanced, PSNR = 29.86 dB (b): ST Decomposition + SP Enhanced, PSNR = 33.28 dB

Image Dehazing Results

Winter is Coming (in Edinburgh)

(a) (b)

Figure 17: (a): Original (b): Non-local Dehazed

Image Dehazing Results - Summary

Strenths and Weaknesses

- Screened Poisson
  - Strengths - General method; fast; good contrast in output
  - Weaknesses - No degradation model, cannot effectively remove haze
- Dark Channel Prior
  - Strengths - Use of degradation model and prior, better haze removal
  - Weaknesses - Prior not valid in some cases, underestimation of transmission
- Non-local Dehazing
  - Strengths - Better prior, best performance of the 3; more robust to patch parameters
  - Weaknesses - Slowest of the 3; does not work when airlight significantly brighter than the scene

Dehazing Video Sequences

Basic Approach

- Dehazing Algorithms are applied on each frame separately

$$J_k(x) = \frac{I_k(x) - A_k(1 - t_k(x))}{t_k(x)}; \qquad k = 1, .., N$$

Drawbacks of the Approach

- No Temporal Coherence
- Lack of Color Consistency
- Long Processing Times

NLD based Spatial-Temporal Fusion Video Dehazing

Video Dehazing Based on Spatial-temporal Information Fusion

- Based on C.Qing et al, "*Underwater video dehazing based on spatial-temporal information fusion*" 2016

Key Aspects

- Transmission map between adjacent frames is similar
- Camera Motion
- Difference in Atmospheric Light

First Frame of Each Segment

Airlight and Transmission Estimation

- Complete Non-Local Image Dehazing algorithm

Transmission Refinement using Guided Filter

- t(x) is not constant in a patch, guided filtering is needed:

$$\tilde{t}_1(x) = \sum_y W_{xy}(I_1)t_1(y)$$

Transmission – Other Frames

Transmission Estimation using NLD

- Linear Interpolation between the first frames of each segment
- Reduces processing time
- Keeps frames coherent (avoid flickering effect)

Transmission Refinement using Guided Filter

- Reduce complexity and preserve color consistency among frames

$$t_k(x) = \sum_y W_{xy}(I_k) t_{k-1}(y)$$

Background Light Estimation

Airlight Estimation

- Airlight is estimated per frame using DC prior
- However, changes in water flowing, camera angles, moving objects, etc cause change in A and produce flickering in video

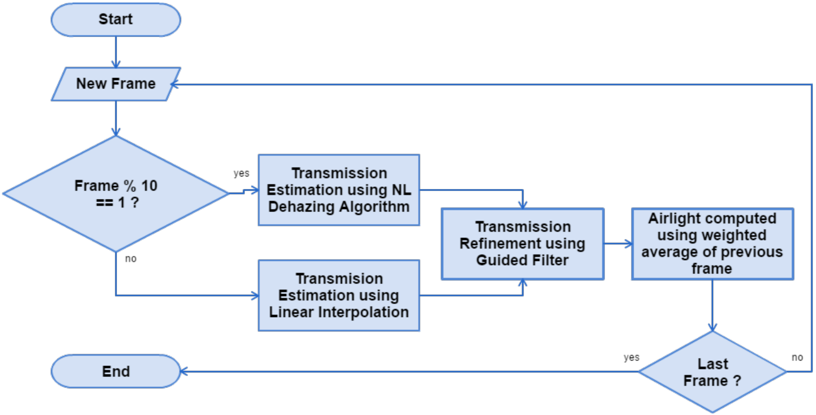
$$\tilde{A}_k = \alpha \tilde{A}_{k-1} + (1-\alpha) A_k$$

Recovering hazy video

- Scene radiance is recovered as follows:

$$J_k(x) = \frac{I_k(x) - \tilde{A}_k}{max(\tilde{t}_k, t_0)} + \tilde{A}_k, \text{ k=1,...,N}$$

Overview of the Method



Experimental Results

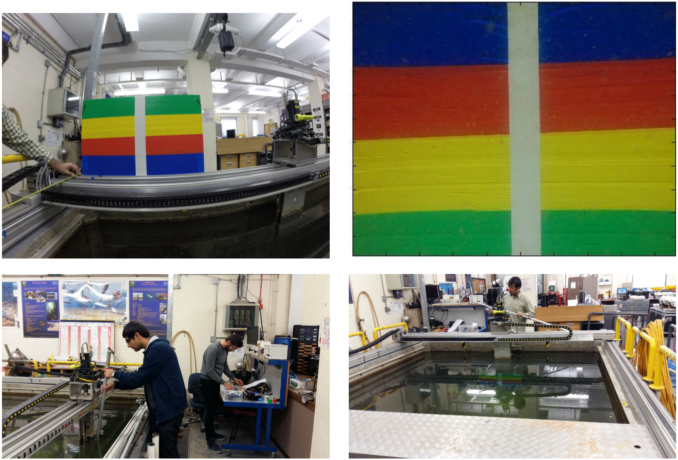


Figure 18: Experimental Results performed in the Ocean's Lab

Results

DEMO VIDEO

Results

(a) (b)

Figure 19: Dehazed Frame 1600 (a): Dark Channel (b): Non-local

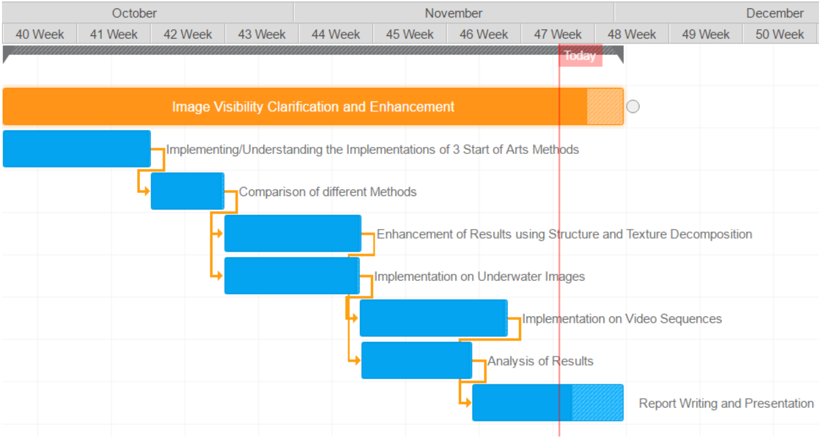
Quantitative measures

Average Gradient (G^c) ↑

	R	G	B
Original Video	1.1605	1.1265	1.1532
Enhanced Video (DC + ST)	1.8653	1.9138	1.9106
Enhanced Video (NL + ST)	**1.9981**	**2.0700**	**2.0721**

Vibot

Working Plan



Conclusion

Image Dehazing

- Comparison of three State of the Art frameworks:
  - Screened Poisson
  - Dark Channel Prior
  - Non-Local Dehazing
- Incorporated Structure-Texture Decomposition
- Underwater Images
- Video Sequences
  - Static images
  - Spatial-Temporal fusion

Future Works

Future Works

- Improve processing time (GPU implementations)
- Quantitative analysis with ground truth
- Test complex models with different transmission coefficients for each color channel
- Integration of different water-based models

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THANK YOU!