Combined stereo reconstruction and defogging

Bezout Labex
Working group "Machine learning and optimization"

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Visual effect of fog

Clear, Visibility distance : 17km

Visual effect of fog

- Color Fades

Visibility distance : 5km

Visual effect of fog

- Color Fades
- Airlight added

Visibility distance : 1km

Visual effect of fog

- Color Fades
- Airlight added
- Contrast and visibility decrease with distance

Visibility distance : 500m

Visual effect of fog

- Color Fades
- Airlight added
- Contrast and visibility decrease with distance

Visibility distance : 250m

⇒ Difficulties for object detection/recognition/identification

Model of fog visual effet

The **Koschmieder law** [Middleton52] :

$$I = I_0 e^{-\beta d} + I_s(1 - e^{-\beta d})$$

Model of fog visual effet

The **Koschmieder law** [Middleton52] :

$$\textcolor{red}{I} = I_0 e^{-\beta d} + I_s(1 - e^{-\beta d})$$

Foggy image $\textcolor{red}{I}$

Model of fog visual effet

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Foggy image I

Image without fog I_0

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Foggy image I

Image without fog I_0

Depth map d

Model of fog visual effet

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Foggy image I

Image without fog I_0

Depth map d

- I_s is the sky intensity

Model of fog visual effet

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Foggy image I

Image without fog I_0

Depth map d

- I_s is the sky intensity
- β is the extinction coefficient (related to the visibility distance)

Model of fog visual effet

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Foggy image I

Image without fog I_0

Depth map d

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$\Rightarrow$ For single image defogging, ambiguity between I_0 and βd

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Foggy image I

Image without fog I_0

Depth map d

- I_s is the sky intensity
- β is the extinction coefficient (related to the visibility distance)

$\Rightarrow$ For single image defogging, ambiguity between I_0 and βd

$\Rightarrow$ When d known, ${\color{red}I_0}$ is computed from estimates of β and I_s

Single image defoging

Foggy image

Visibility restoration using CNN
AOT-Net [Li-ICCV17]

- Many variants

Single image defoging

Foggy image

Visibility restoration using [Tarel-ICCV09]

- Many variants
- Atmospheric veil $I_s(1 - e^{-\beta d})$ estimated from the pixels white amount

Single image defoging

Foggy image

Visibility restoration using Dark Chanel Prior [He-CVPR09]

- Many variants
- Atmospheric veil $I_s(1 - e^{-\beta d})$ estimated from the pixels white amount
- Filtering and guided filtering [He-PAMI13,Caraffa-IP15]

Single image defoging

Foggy image

Visibility restoration using [Caraffa-IP15]

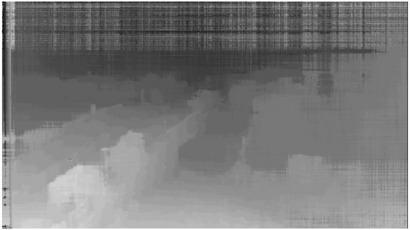
- Many variants
- Atmospheric veil $I_s(1 - e^{-\beta d})$ estimated from the pixels white amount
- Filtering and guided filtering [He-PAMI13,Caraffa-IP15]
- Reverse Koschmieder law from the atmospheric veil

Fog in stereo reconstruction

Left stereo image

Right stereo image

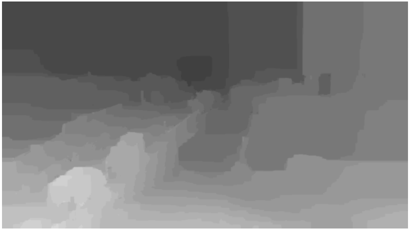
Fog in stereo reconstruction



Estimated disparity map using SGM [Hirschmuller-PAMI08]

Right stereo image

Fog in stereo reconstruction



Estimated disparity map with GC [Boykov-PAMI01]

Right stereo image

- Problem : a wall is reconstructed before visibility distance due to decreasing contrast with distance

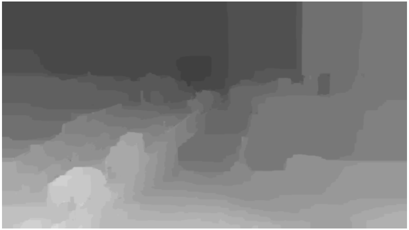
Fog in stereo reconstruction

Single Image defogging

Right stereo image

- Problem : a wall is reconstructed before visibility distance due to decreasing contrast with distance
- However, available information at far distances not used

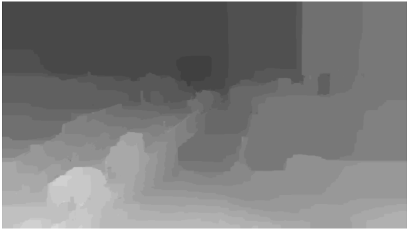
Depth cues



Stereo reconstruction

Depth cues

Virgin of the Rocks (Da Vinci, 1507)

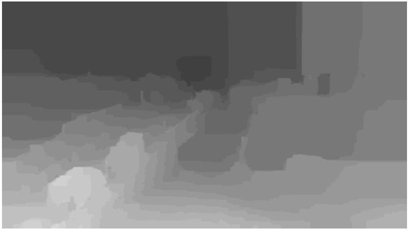


Stereo reconstruction

- The intensity is related to the depth at far distances

Depth cues

Landscape of Virgin of the Rocks (Da Vinci, 1507)

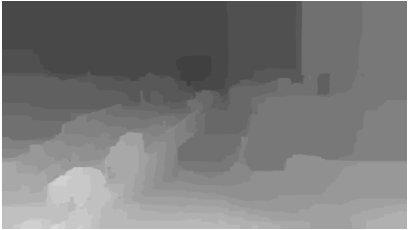


Stereo reconstruction

- The intensity is related to the depth at far distances

Depth cues

Atmospheric veil after thresolding



Stereo reconstruction

- The intensity is related to the depth at far distances
- Complementary depth cues are provided by fog and stereovision

Depth cues

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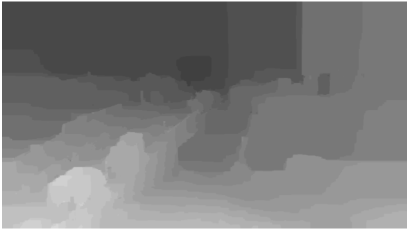

Stereo reconstruction

- The intensity is related to the depth at far distances
- Complementary depth cues are provided by fog and stereovision
- $\Rightarrow$ Usefull combination

Towards a MRF model

- Stereovision without fog

Towards a MRF model

- Stereovision without fog
- Single image defogging knowing the depth

Towards a MRF model

- Stereovision without fog
- Single image defogging knowing the depth
- Global model combining defogging and stereovision

What we are looking for?

I_L

I_R

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I_L

I_R

I_{0L}

D

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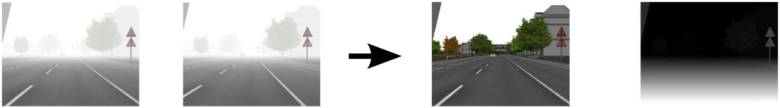

I_L I_R I_{0L} D

Bayesian approach :

$$p(D, I_{0L} | I_L, I_R) \propto p(I_L, I_R | D, I_{0L}) \; p(D, I_{0L})$$

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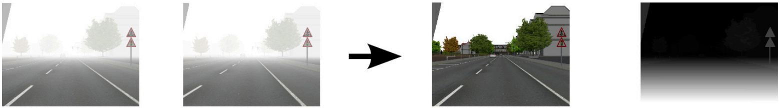
$$E(D, I_{0L} | I_L, I_R) = \underbrace{E(I_L, I_R | D, I_{0L})}_{E_{data}} + \underbrace{E(D, I_{0L})}_{E_{prior}} \tag{1}$$

What we are looking for?



I_L I_R I_{0L} D

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$$E(D, I_{0L} | I_L, I_R) = \underbrace{E(I_L, I_R | D, I_{0L})}_{E_{data}} + \underbrace{E(D, I_{0L})}_{E_{prior}} \qquad (1)$$

MAP estimate $\Rightarrow$ Find D and I_{0L} which minimize E.

Dense stereo reconstruction without fog

Without fog, $I_{0L} \approx I_L$:

Dense stereo reconstruction without fog

Without fog, $I_{0L} \approx I_L$:

$$E(D|I_L, I_R) = \underbrace{E(I_R, I_L|D)}_{E_{data\_stereo}} + \underbrace{E(D)}_{E_{prior\_stereo}} \tag{2}$$

Dense stereo reconstruction without fog

Without fog, $I_{0L} \approx I_L$:

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$$E_{prior\_stereo} = \lambda_D \sum_{(i,j)\in X} \sum_{(k,l)\in N} |D(i,j) - D(i+k, j+l)|$$

Single image defogging knowing the depth

When depth $d = \frac{\nu}{D}$ is known :

$$E(I_0|D, I) = \underbrace{E(I|D, I_0)}_{E_{data\_fog}} + \underbrace{E(I_0|D)}_{E_{prior\_fog}} \quad (3)$$

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$$E_{data\_fog} = \sum_{(i,j)\in X} \rho_P\left(\frac{|I_0(i,j)e^{-\frac{\beta\nu}{D(i,j)}} + I_s(1 - e^{-\frac{\beta\nu}{D(i,j)}}) - I(i,j)|}{\sigma_P}\right)$$

- ρ_p is related to the assumed noise distribution

Single image defogging knowing the depth

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$$E_{prior\_fog} = \lambda_{I_0} \sum_{(i,j)\in X} \sum_{(k,l)\in N} |I_0(i,j) - I_0(i+k, j+l)|$$

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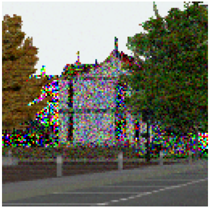
- ρ_p is related to the assumed noise distribution
- Factor $e^{-\frac{\beta\nu}{D(i,j)}}$ into the prior term

Effect of the factor in the prior

$$E_{prior\_fog} = \lambda_{I_0} \sum_{(i,j)\in X} \sum_{(k,l)\in N} |I_0(i,j) - I_0(i+k, j+l))|$$

$\lambda_{I_0} = 0$



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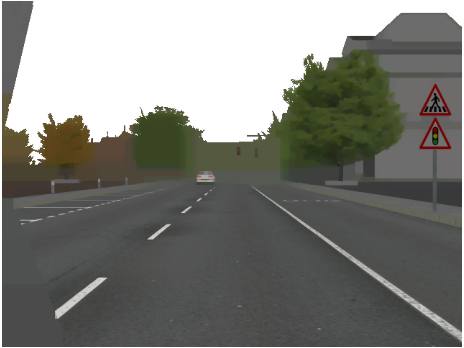
$\lambda_{I_0} = 1$



Effect of the factor in the prior

$$E_{prior\_fog} = \lambda_{I_0} \sum_{(i,j)\in X} \sum_{(k,l)\in N} e^{-\frac{\beta\nu}{D(i,j)}} \left| I_0(i,j) - I_0(i+k, j+l) \right|$$

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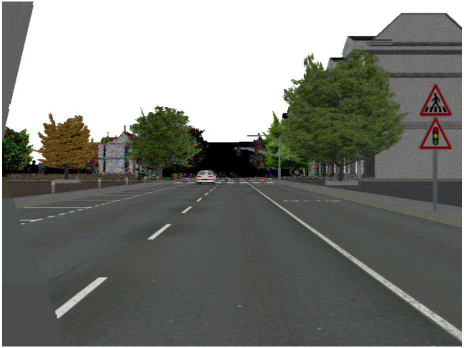

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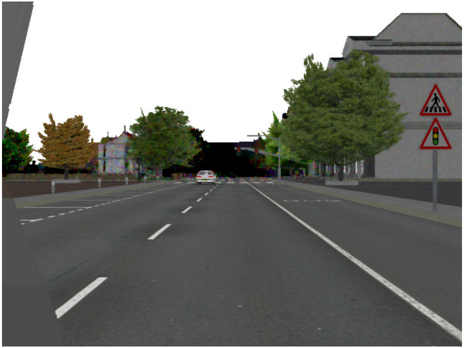
$$\lambda_{I_0} = 2$$



Effect of the factor in the prior

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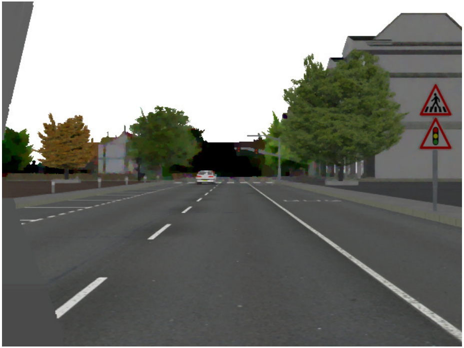
$\lambda_{I_0} = 4$



Effect of the factor in the prior

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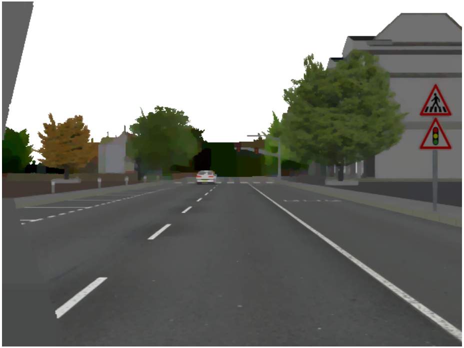
$\lambda_{I_0} = 8$



Stereo reconstruction and defogging : Data term

$$E_{data\_fog\_stereo} = \sum_{(i,j)\in X} \rho_P\left(\frac{|I_{0L}(i,j)e^{\frac{-\beta\nu}{D(i,j)}} + I_s(1 - e^{\frac{-\beta\nu}{D(i,j)}}) - I_L(i,j)|}{\sigma_P}\right) + \rho_P\left(\frac{|I_{0L}(i,j)e^{\frac{-\beta\nu}{D(i,j)}} + I_s(1 - e^{\frac{-\beta\nu}{D(i,j)}}) - I_R(i - D(i,j), j)|}{\sigma_P}\right) \quad (4)$$

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$$E_{data^*} = \alpha E_{data\_stereo} + (1-\alpha)E_{data\_fog\_stereo}$$

Stereo reconstruction and defogging : Data term

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$$E_{data^*} = \alpha E_{data\_stereo} + (1-\alpha) E_{data\_fog\_stereo}$$

$$E_{data} = \begin{cases} E_{data^*} & \text{if } I_L(i,j) \neq I_s \\ 0 & \text{else. } I_L(i,j) = I_s \text{ and } D(i,j) = 0 \end{cases}$$

Complete energy and optimization

$$\begin{aligned}\operatorname*{argmin}_{D, I_{0L}, \sigma_p} E = & \alpha E_{data\_stereo}(D) + (1-\alpha) E_{data\_fog\_stereo(I_{0L}, D, \sigma_p)} \\ & + \lambda_D E_{prior\_stereo}(D) + (1-\alpha)\lambda_{I_{0L}} E_{prior\_fog}(I_{0L}, D)\end{aligned} \quad (5)$$

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- α and λ_D are hyper-parameters, $\lambda_{I_{0L}} = 1$

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- D Approximated by an initial $\ddot{D}$ to simplify optimization

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- Alternate optimization with respect to D

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Complete energy and optimization

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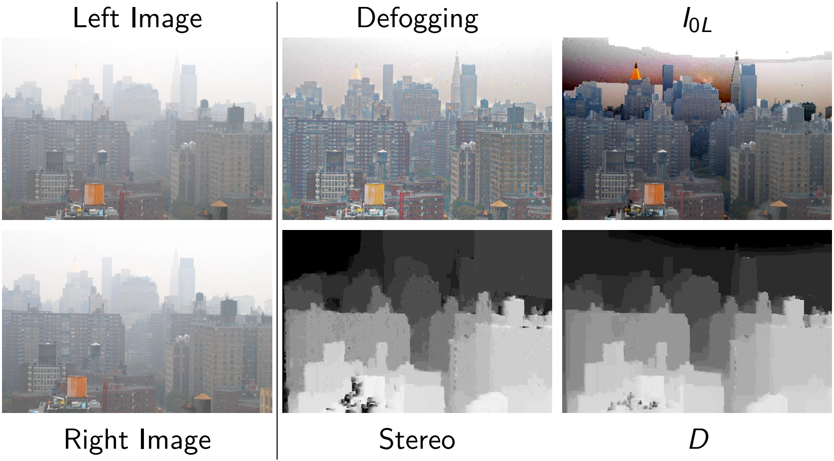
- α and λ_D are hyper-parameters, $\lambda_{I_{0L}} = 1$
- D Approximated by an initial $\ddot{D}$ to simplify optimization
- Alternate optimization with respect to D and I_{0L}
- Estimate σ_p like in [Nishino-IJCV12]

Results on real images



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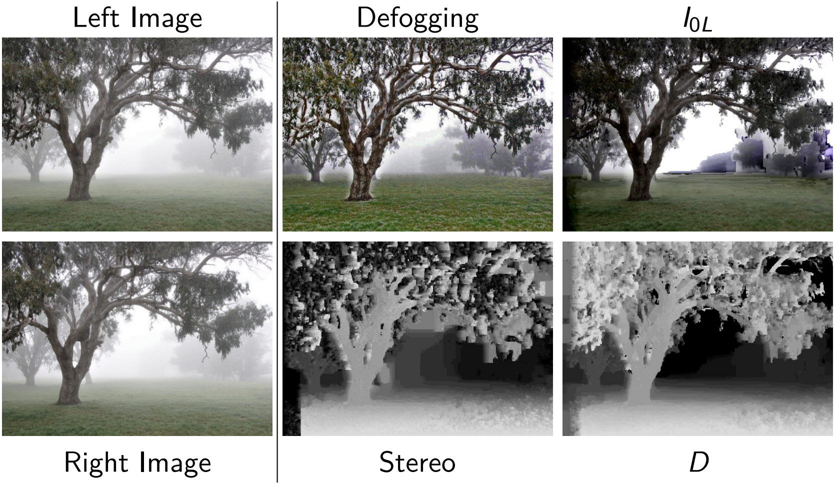

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- Thanks to complementary depth cues between stereovision and fog, defogging and stereo reconstruction can be combined with advantages

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- More details in [Caraffa-CVA14, Caraffa-ACCV12]

Thank you