BACKGROUND LIGHT ESTIMATION FOR DEPTH-DEPENDENT UNDERWATER IMAGE RESTORATION

CIS centre for intelligent sensing

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1. Introduction

Light attenuation degrades scene appearance

- Scattering → lack of contrast
- Absorption → reduced colour intensity
- Depends on wavelength and water composition
- More observable for red light in open ocean water [1]
- Quantified by attenuation coefficient β
- Residual intensity after distance $d = e^{-\beta d}$ [2]
- Significant effect over large vertical depth range

Objective

- To compensate for colour loss along scene-to-camera distance
  - To restore the appearance of scene as closer to camera
- To preserve the colour of water

2. Underwater image formation model [1]

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

Captured image: $I(x,y)$

Transmission map: $t(x,y)$
- Depends on scene-to-camera distance $d(x,y)$ and β
- $t(x,y) = e^{-\beta d(x,y)}$ [2]

Scene radiance: $J(x,y)$
- Non-attenuated propagation path to camera
- To be recovered

Background light: $A(x,y)$
- Introduces veiling effect
- Often assumed to be uniform $\boldsymbol{A}$

Challenges

- Underdetermined system, often overcompensates for red intensity channel
- Non-uniform $A(x,y)$: unknown β and vertical depth range

3. Proposed method

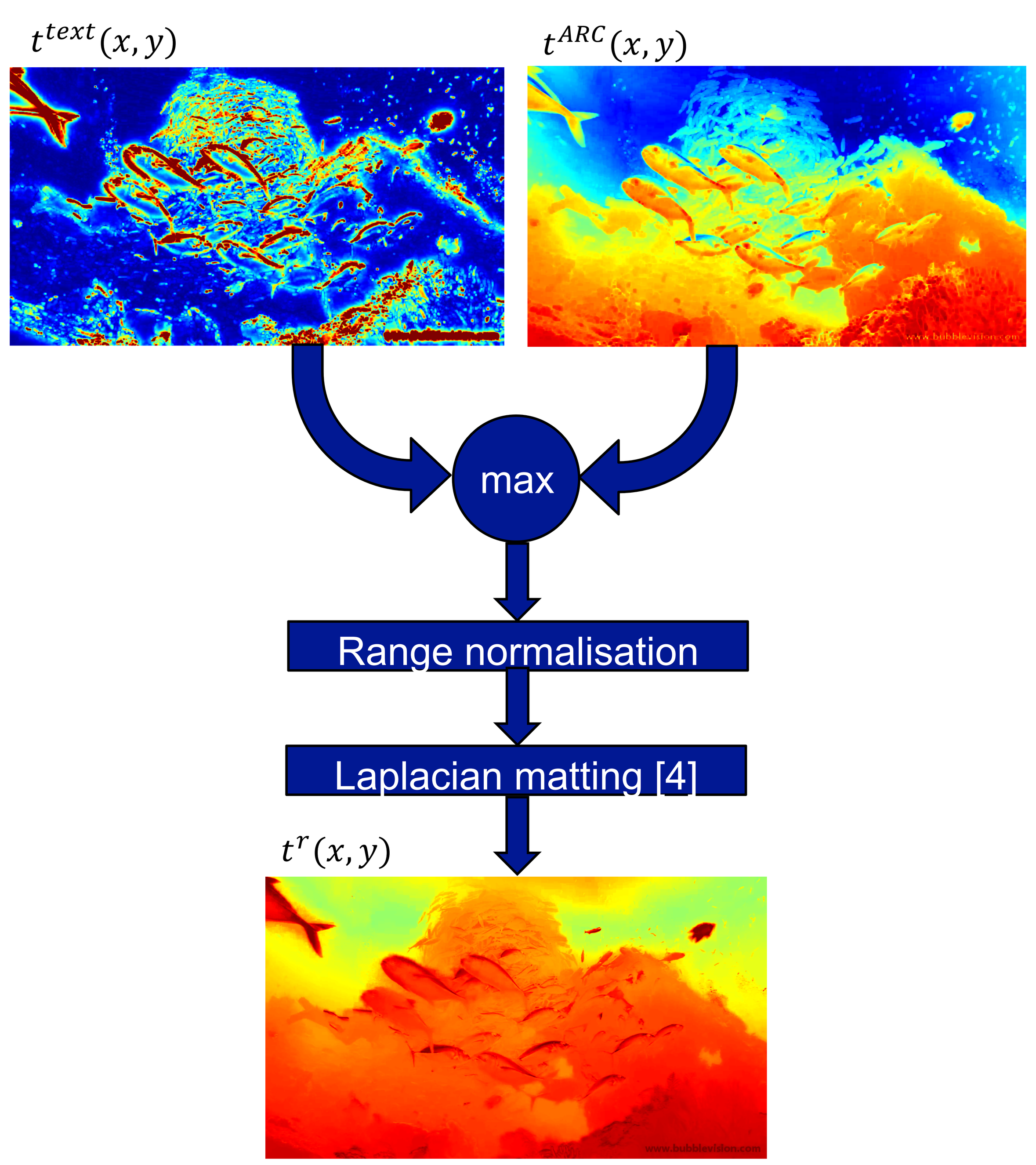
Estimation of $t(x,y)$

- Different for each colour channel
  - Derive $t^g(x,y)$ and $t^b(x,y)$ from $t^r(x,y)$
- Estimation of $t^r(x,y)$
  - Complementary information from attenuation
    - Scattering $t^{text}(x,y)$: Laplacian pyramid
    - Absorption $t^{ARC}(x,y)$: Red Channel Prior [3]

$$\min\left(1 - I^r(x,y), I^g(x,y), I^b(x,y)\right) \to 0$$

  - To avoid overcompensating red intensity channel

$$\tilde{t}^r(x,y) = \max\left(t^{text}(x,y), t^{ARC}(x,y)\right)$$



Estimation of $A(x,y)$

- Select A from candidate regions
  - Constraints for candidates of $\boldsymbol{A}$
    - Ratio constraint from oceanology study [5]: green or blue colour

$$\frac{A^r}{A^g} < 0.9101 \quad \text{and} \quad \frac{A^r}{A^b} < 0.8280$$

    - Variance constraint: flat region
  - Candidate regions: region proposals [6] with 50% pixels fulfilling both constraints
  - Select $\boldsymbol{A}$ from pixel location

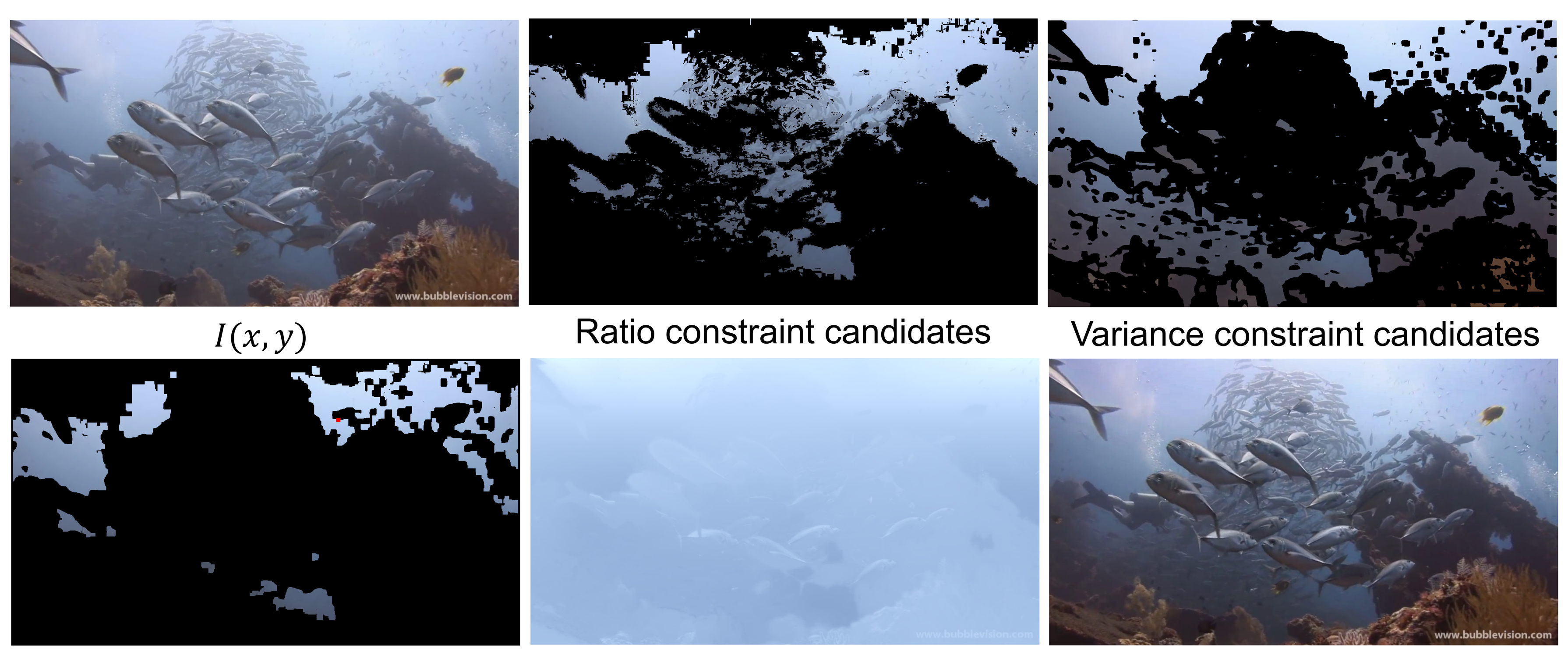
$$(x^*, y^*) = \underset{(s,t)\in I(x,y)}{\arg\max} \left(\max\left(I^g(s,t), I^b(s,t)\right) - I^r(s,t)\right)$$

- Estimate $A(x,y)$
  - Attenuation coefficient per pixel distance $\hat{\beta}$ for water pixels
  - Any water pixel D pixels below $\boldsymbol{A}$

$$A(x,y) = \boldsymbol{A}e^{-\hat{\beta}D} \;\rightarrow\; \ln A(x,y) = \ln \boldsymbol{A} - \hat{\beta}D$$

  - Obtain $\hat{\beta}$ by linear regression with L_1 loss
  - Account for discontinuity in scene-to-camera distance

$$A(x,y) = \boldsymbol{A}\exp\left(-\hat{\beta}(x - x^*)\frac{\ln t^r(x,y)}{\ln t^r(x^*,y^*)}\right)$$



4. Evaluation

Criteria

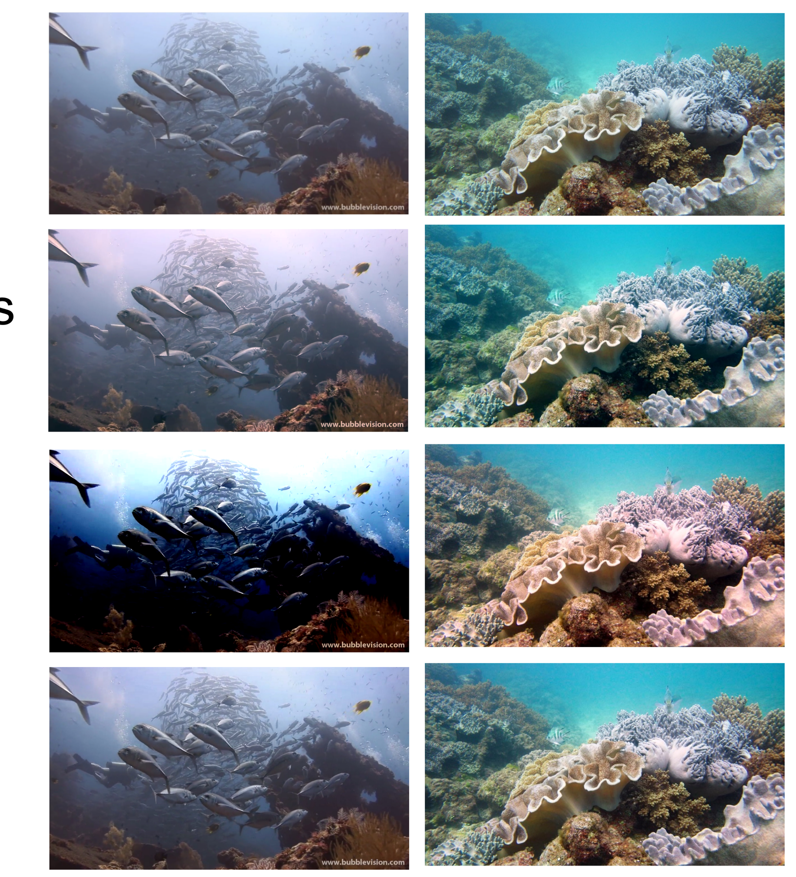
- Preservation of the colour of water
  - Mean Square Error (MSE) of manually segmented water pixels before and after restoration
- Online subjective experiment (Subj.)
  - Compare with the original image, select 'the *most attractive image*' from all restored images
  - Report average % of method being selected

Experiment

- 60 test images collected online
- Each image evaluated ≥ 18 times in Subj.

Results

	WCID [7]	BLA [8]	Proposed
MSE (unit = 0.01)	1.90	1.12	***0.14***
Subj. (%)	16.9	***30.9***	16.9



5. Conclusion

- Restore appearance for non-water scenes without overcompensating for red intensity channel
- Preserve the colour of water by
  - Physics based selection of global background light A
  - Estimation of non-uniform background light $A(x,y)$ without prior knowledge

Online Demonstration

Reference

[1] Schechner and Karpel, "Clear underwater vision," in CVPR 2004.
[2] Swinehart, "The Beer-Lambert law," in J. Chem. Educ. 1962.
[3] Galdran et al.,"Automatic Red-Channel underwater image restoration," in J. Visual Comm. And Image Representation 2015.
[4] Levin et al., "A closed form solution to natural image matting," in TIP 2007.
[5] Zhao et al.,"Deriving inherent optical properties from background color and underwater image enhancement," in O. Eng 2014.
[6] Pont-Tuset et al.,"Multiscale combinatorial grouping for image segmentation and object proposal generation," in TPAMI 2017.
[7] Chiang and Chen,"Underwater image enhancement: Using wavelength compensation and image dehazing," in TIP 2012.
[8] Peng and Cosman, "Underwater image restoration based on image blurriness and light absorption," in TIP 2017.