SELECTIVE COLOUR RESTORATION OF UNDERWATER SURFACES

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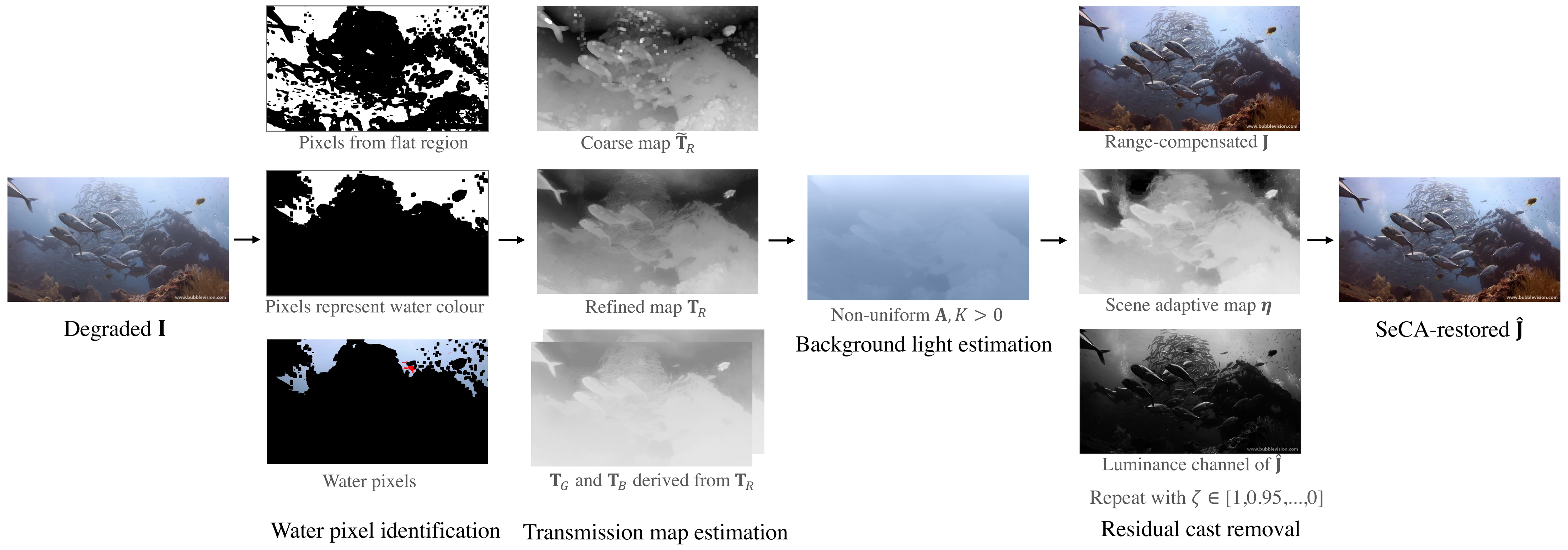
1. Introduction

- Underwater images (capture surfaces and water mass) degraded by light attenuation
- Light attenuation depends on distance travelled by light (depth, range) and wavelength
  - surfaces under large depth are under considerable colour cast
  - water colour in image could be non-uniform
- Existing methods
  - mostly addresses degradation along range only & assume uniform water colour in image
  - few methods remove colour cast along depth but also distort water colour
- Goal: restores colour as if surfaces are captured in air & maintain water colour

2. SeCA

- Physics-based method to restore colour in degraded image $\mathbf{I}$ along range & depth



Restoration along the range

- Range-compensated image $\mathbf{J}$ appears as if no water between surface and camera
- Obtain $\mathbf{J}$ using the Schechner-Karpel model [1]:

$$\mathbf{I} = \mathbf{T} \cdot \mathbf{J} + (\mathbf{1} - \mathbf{T}) \cdot \mathbf{A}$$

with *to-be-estimated* transmission map $\mathbf{T} = e^{-\beta z} \in [0, 1]$ and background (ambient) light $\mathbf{A}$

- Address wavelength-dependency of $\mathbf{T}$
  - estimate $\mathbf{T}_\mathrm{R}$ from Red Channel Prior [2]
  - obtain $\mathbf{T}_k = (\mathbf{T}_\mathrm{R})^{\beta_k/\beta_R}, k \in \{G, B\}$
- $\mathbf{A}$ represents the water mass i.e. water colour
  - Derive colour ratio constraint to identify water pixels
    → representative water colour $\mathbf{A}^*$ at pixel location (x^*, y^*)
  - Address non-uniform $\mathbf{A}$ by estimating *attenuation coefficient per pixel distance* K and interpolating as

$$\mathbf{A}(x, y) = \mathbf{A}^* \exp\left(-\frac{\ln \mathbf{T}}{\ln \mathbf{T}^*} K(y - y^*)\right)$$

→ Also handles uniform $\mathbf{A}$ (when $K = 0$)

2. SeCA (cont.)

Residual colour-cast removal

- Restore $\hat{\mathbf{J}}$ as if surfaces are under an unattenuated target illuminant $(\rho_t, \gamma_t, \beta_t)$, e.g. D65, with chromatic adaptation [3]:

$$\hat{\mathbf{J}} = \mathcal{M}^{-1}\mathcal{D}\mathcal{M}\mathbf{J}$$

where $\mathcal{M}$ maps the colour into LMS colour space, diagonal matrix $\mathcal{D}$ scales the intensity in each channel to achieve the same cone response

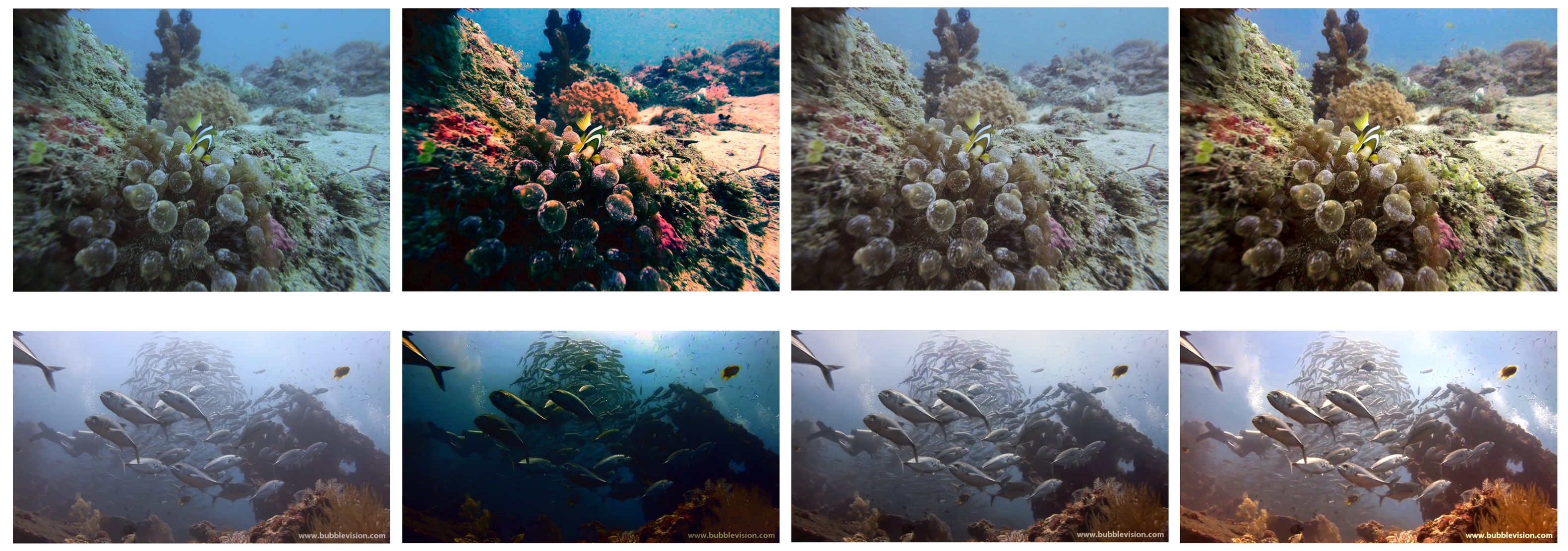
- *Selectively* remove cast from surfaces under (source) attenuated illuminant $(\rho_s, \gamma_s, \beta_s)$

$$\mathcal{D} = \mathrm{diag}\big((\rho_t/\rho_s)^\eta, (\gamma_t/\gamma_s)^\eta, (\beta_t/\beta_s)^\eta\big), \eta \in [0,1]$$

- Control cast removal extent of each pixel with η derived from transmission map of $\mathbf{J}$
  - surfaces have η values close to 1 (full cast removal)
  - water mass has η values close to 0 (no cast removal)
- Estimate attenuated illuminant as $\mathbf{A}^\zeta$ → choose largest ζ with no over-exposure

3. Validation

- Compared with physics-based & neural networks
- SeCA shows consistent results in shallow and deep water, and non-uniform water colour
- Stability demonstrated by direct extension to video



Degraded | UWHL [4] | Ucolor [5] | SeCA

Video & Code

4. Conclusion

- SeCA addressed two issues in state-of-the-art
  - non-uniform water colour in restoration along range
  - removal of residual colour cast from surfaces without distorting the water colour
- SeCA demonstrated how combining oceanic domain knowledge and image processing technique could outperform neural network, when ideal training data is scarce

Reference

[1] Schechner and Karpel, 'Clear underwater vision', CVPR 2004
[2] Galdran et al., 'Automatic Red-Channel underwater image restoration', JVCIR 2015
[3] Gijsenij,et al., 'Computational color constancy: Survey and experiments', TIP 2011
[4] Berman et al., 'Underwater Single Image Color Restoration Using Haze-Lines and a New Quantitative Dataset', PAMI 2021
[5] Li et al., 'Underwater image enhancement via medium transmission-guided multi-color space embedding', TIP 2021