Estimating Absorption Coefficient from a Single Image via Entropy Minimization

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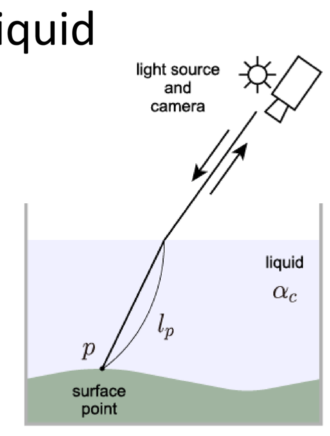
Goal and Contributions

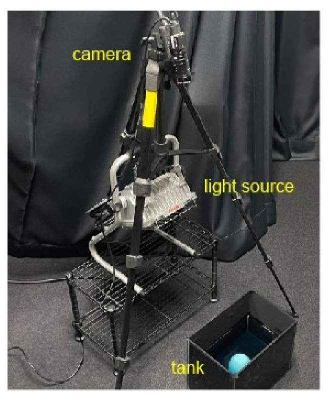
◆ Goal

Estimating absorption coefficient of an unknown liquid in a passive and non-contact manner

Input:
–a single color image taken from the outside of the liquid

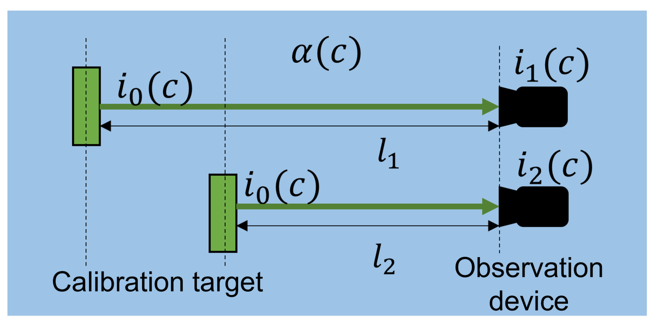
Output:
–three-band (RGB) absorption coefficient: $(\alpha_R, \alpha_G, \alpha_B)$

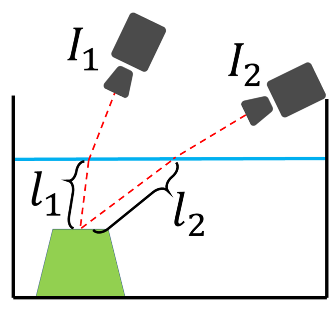




◆ Related Work

- Use of calibration target at known distances: requires external hardware and distance measurement
- Passive and non-contact approach: requires two hyperspectral images taken from different viewpoints





◆ Main Contributions

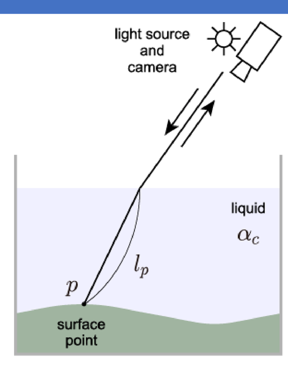
- Novel and easy-to-use method
  - we estimate three-band absorption coefficient from a single color image in a passive and non-contact manner
- Ambiguity analysis
  - we show the ambiguity in the estimated absorption coefficient and reveal the effects of the ambiguity on the applications
- Effective and useful method
  - we confirmed that our method works well for real images and is useful for under-liquid image/scene analysis

Proposed Method

◆ Difficulties

- Absorption model
  - Lambert-Beer law

$$i_{pc} = g_p s_c r_{pc} e^{-2\alpha_c l_p}$$

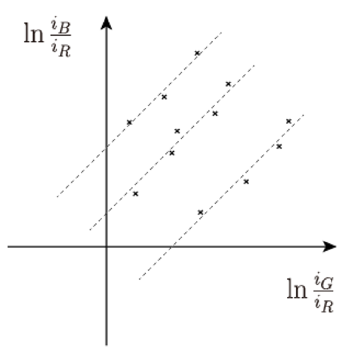


- Ill-posed problem
  - three constraints(pixel color) per pixel: i_{pc}
  - many overall / per pixel unknows: absorption coefficient α_c, per-pixel optical path length l_p, per-pixel geometric term g_p, and per-pixel surface reflectance r_{pc}

◆ Key Insight :Log of chromaticity band-ratio space

- surface points with the same reflectance r_{pc} but different depth l_p distribute along a straight line

$$\begin{pmatrix} \log \frac{i_{pB}}{i_{pR}} \\ \log \frac{i_{pG}}{i_{pR}} \end{pmatrix} = \begin{pmatrix} \log \frac{s_B r_{pB}}{s_R r_{pR}} \\ \log \frac{s_G r_{pG}}{s_R r_{pR}} \end{pmatrix} - 2 l_p \begin{pmatrix} \alpha_B - \alpha_R \\ \alpha_G - \alpha_R \end{pmatrix}$$



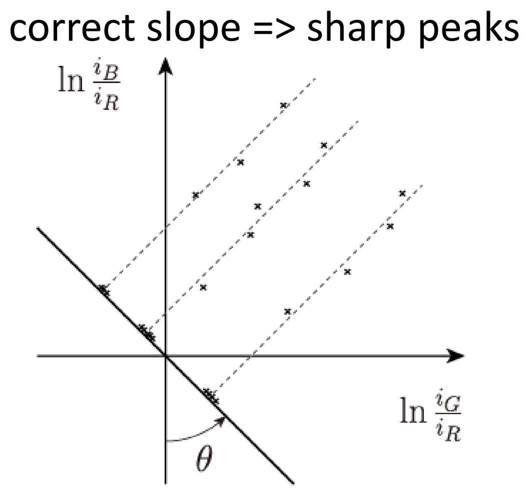
- band-ratio => cancel geometric terms out
- log => linear to absorption coefficient

slope of parallel lines ⇔ absorption coefficient

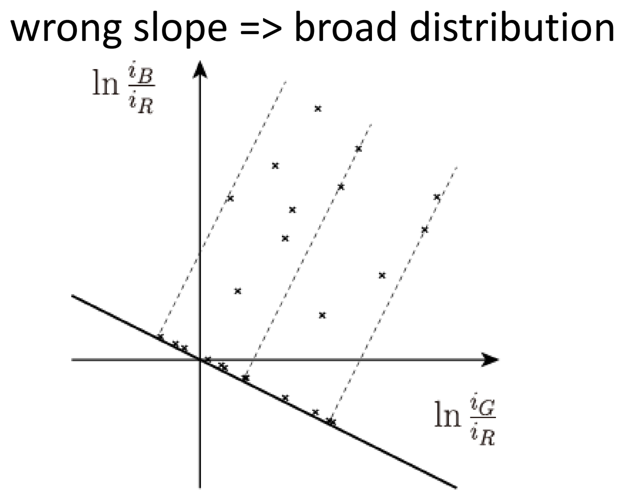
◆ Proposed Method

- Estimating the slope of parallel lines
- projecting points to 1D line perpendicular to slope

correct slope => sharp peaks



wrong slope => broad distribution



=> entropy minimization

◆ Ambiguity

we estimate the normalized absorption coefficient such that

$$\alpha_R + \alpha_G + \alpha_B = 1$$

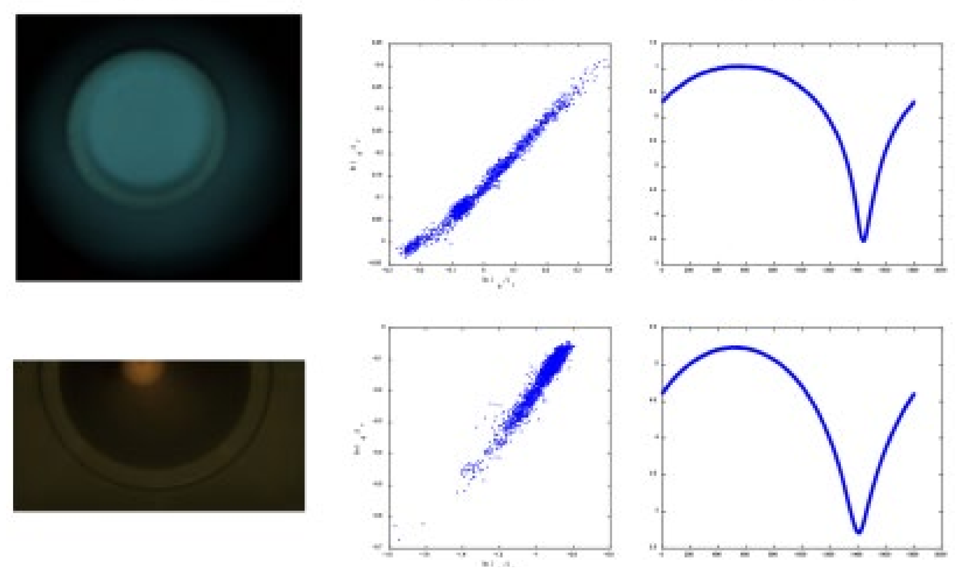
thus, we obtain relative absorption coefficient with 1-DoF ambiguity:

$$\alpha_G = \frac{(\sin\theta - 2\cos\theta)\alpha_R + \cos\theta}{\cos\theta + \sin\theta},$$

$$\alpha_B = \frac{(\cos\theta - 2\sin\theta)\alpha_R + \sin\theta}{\cos\theta + \sin\theta}.$$

◆ Experimental Results: Absorption Coefficient

- Pipeline of our method and estimated absorption coefficient



	scene I			scene II		
	GT	w	w/o	GT	w	w/o
α_R	0.60	0.67	0.60	0.53	0.83	0.54
α_G	0.28	0.29	0.30	0.29	0.17	0.27
α_B	0.12	0.04	0.10	0.17	0.00	0.20

– fix the ambiguity in the estimated absorption coefficient (w)
by using the G.T. and obtain the absorption coefficient(w/o)

=> The deviation from G.T. can be explained by the 1-DoF ambiguity

Applications

◆Shape Recovery

- we can reconstruct per-pixel depth of an under-liquid scene up to an overall scale ambiguity

$$l_p = \frac{1}{2(\alpha_R - \alpha_B)} \left(\log \frac{i_{pB}}{i_{pR}} - \log \frac{s_B}{s_R} + \log \frac{r_{pB}}{r_{pR}} \right)$$

- we need to take the difference in per-pixel reflectance

=> we estimate the bias of each reflectance by L1 norm minimization

- we can fix overall bias from a surface crossing the border between a liquid and air.

◆Absorption Removal

- we can recover absorption-free image without ambiguity

$$i'_{pc} = i_{pc} e^{2\alpha_c l_p}$$

- the attenuation due to absorption depends on the product of the absorption coefficient and the depth

=> the ambiguity of the scale in the absorption coefficient and in the depth is canceled out each other

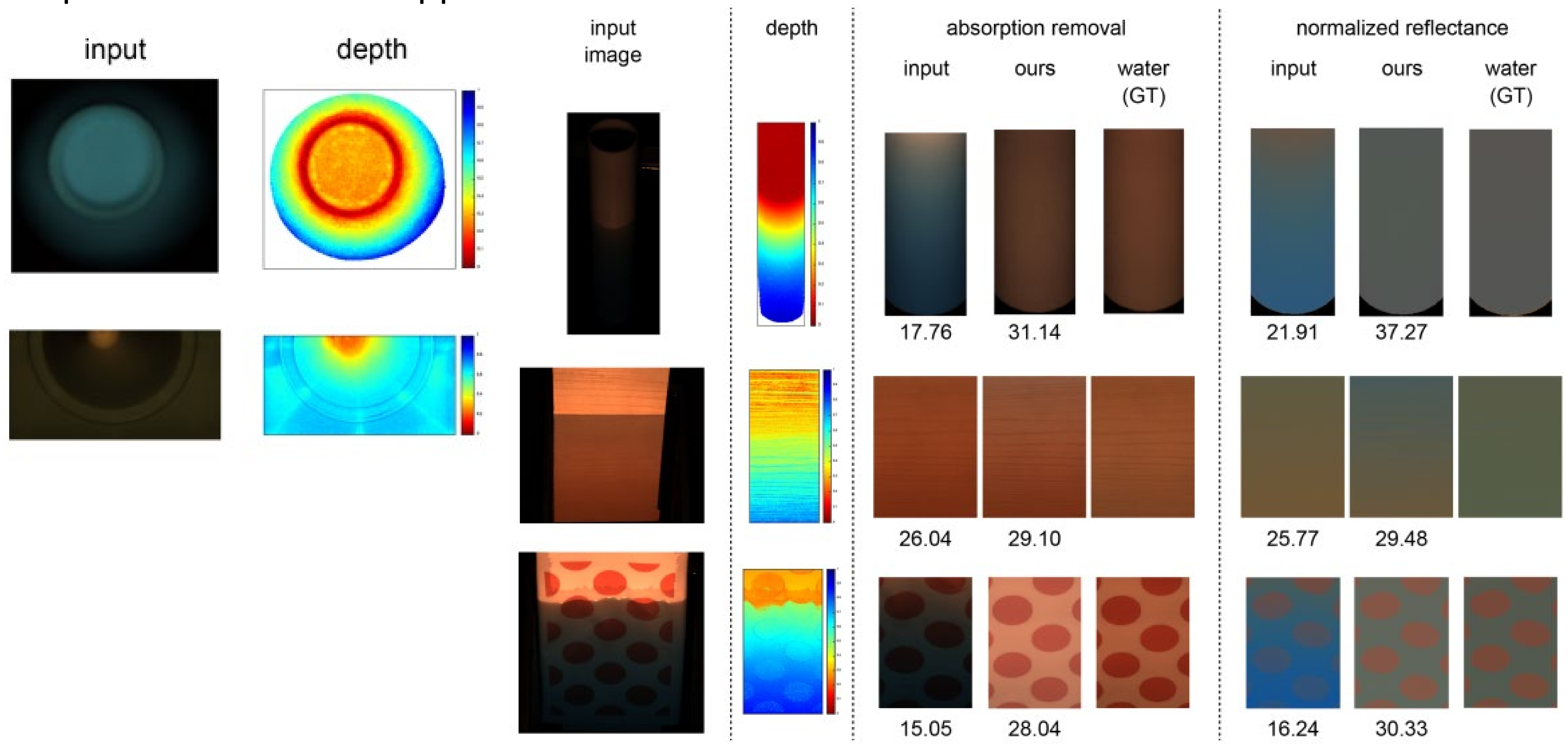
◆Reflectance Recovery

- we can recover per-pixel normalized reflectance without ambiguity

$$r_{pc} = \frac{i'_{pc}}{g_p s_c} = \frac{1}{g_p} \cdot \frac{1}{s_c} i'_{pc}$$

- we can obtain the per-pixel normalized reflectance without ambiguity, if the light source color is known

◆Experimental Results: Applications



- the numerical values below each result image are PSNRs (higher is better)
- we confirm qualitatively and quantitatively that the estimated absorption coefficient is useful for under liquid shape recovery, absorption removal, and reflectance recovery

=> Estimated absorption coefficient is useful for image/scene analysis although it has 1-DoF ambiguity

Future Work

- Improvement of estimation accuracy
- Extension to scattering medium