Practical acquisition of translucent liquids using polarized transmission imaging

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(a) Liquids exhibiting absorption (b) Liquids exhibiting absorption and scattering

Figure 1: Acquired translucent liquids rendered lit with two frontal area light sources. (a) (left to right): chardonnay, cognac, whiskey, olive oil, rosé, sunflower oil, and vinegar. (b) (left to right): cocktail (vodka+orange juice), cherry juice, sesame oil, kiwi juice, merlot, apple juice, and mango juice.

CCS CONCEPTS

• **Computing methodologies → Visibility**;

KEYWORDS

transmission, polarization, absorption, scattering, refractive index

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1 INTRODUCTION

We present a novel, practical method for acquisition of optical properties of common everyday translucent liquids using a simple acquisition setup involving an LCD panel. Previous work on acquiring liquids has required specialized procedures such as dyeing with a fluorescent agent [Ihrke et al. 2005] for volumetric reconstruction of liquid flow, or dilution of liquid in a specialized water tank [Narasimhan et al. 2006] for acquiring its optical properties for rendering. In this work, we build upon the recent work of Kim et al. [2017] who employ direct transmission imaging for single-view reconstruction of axially-symmetric transparent objects such as glasses, goblets, carafes, etc. We observe that many optically interesting everyday liquids such as cocktails, juices, whiskey, wine, oil, etc., are commonly contained in such axially-symmetric transparent containers. Hence, we propose a much more natural acquisition process where we image the transmission of backlit illumination through a liquid volume contained in such a glass object to estimate its optical properties including its absorption and scattering coefficients, and refractive index. Figure 1 demonstrates renderings of various acquired translucent liquids with our proposed method separated into two types: those exhibiting only absorption (a), and those that exhibit both absorption and scattering (b).

2 ESTIMATING ABSORPTION

We employ a very simple acquisition setup with a camera imaging a liquid volume contained in a glass container which is backlit with constant uniform illumination using an LCD panel. We assume the glass container's inner and outer geometry and refractive index are already known using the method of [Kim et al. 2017]. We take three photographs with this setup: a reference with the camera directly imaging the LCD panel illumination, a second photograph of the empty glass object backlit with LCD illumination, and a third photograph of the glass object containing a liquid volume. We denote these photographs as I_r, I_g, and I_l respectively. We employ I_r to white balance the images and take the ratio of I_g/I_r and average within a region of interest (ROI) to obtain the normalized transmissive color of the glass object. Finally, we estimate the absorption coefficient σ_a of a clear liquid by inverting Beer's Law and averaging within the ROI:

$$\sigma_a = average\left\{-\frac{1}{d_l(u,v)} ln \frac{I_l(u,v)}{I_g(u,v)}\right\}, \tag{1}$$

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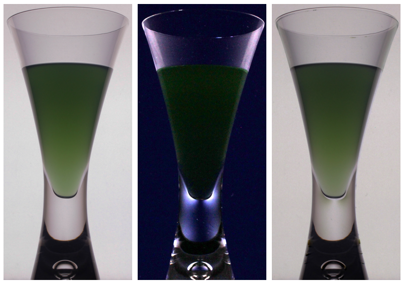
where $d_l(u,v)$ is the distance of light transport through the liquid volume for a camera ray (u,v). Both the estimated glass transmission and liquid absorption were employed in the rendering in Fig. 1, (a).

3 ESTIMATING SCATTERING



(a) Parallel pol. (b) Cross pol. ×5 (c) (a) - (b)

Figure 2: Two photographs, (a) and (b), taken for kiwi juice in a cocktail glass under parallel and cross polarization, respectively. Subtracting (b) from (a) isolates direct transmission + single scattering (c).

Many translucent liquids have a cloudy appearance and exhibit both absorption and scattering. In their natural concentration, such liquids exhibit multiple scattering which highly complicates the image formation model. To overcome this, Narasimhan et al. [2006] diluted liquids to only measure single scattering within the liquid volume. Instead, in our setup we rely on the inherent polarization of the LCD panel illumination and apply polarization difference imaging on the light transmitted through a cloudy liquid volume. The central premise is that direct transmission and single scattering of light through the liquid volume preserves polarization while multiple scattering depolarizes. Thus, the polarization difference image isolates the transmitted direct + single scattering components (Fig. 2).

Thereafter, we apply a very similar image formation model for single scattering as in [Narasimhan et al. 2006]. However, unlike Narasimhan et al.'s usage of a point light source inside the scattering medium, we model single scattering of liquid volume inside our glass container due to a backlit area light source (LCD panel). Our area source is advantageous for achieving higher SNR for polarization imaging. We construct an error function between our modeled equations for direct and single scattering components, E_d and E_s respectively in Eq. 2, and the measured pixel intensities within the ROI of the direct component image (Fig. 2, c). Note that σ_t and β in Eq. 2 refer to the extinction and scattering coefficients respectively, which are estimated by minimizing our error function. We also estimate the scattering anisotropy parameter g as part of this error minimization.

$$\begin{aligned} E_d(u,v) &= \frac{I_0}{4(r^2 - x_l^2)} e^{-2\sigma_t \sqrt{r^2-x_l^2}} \\ E_s(u,v) &= \beta \int_{x_l}^{x_h} \frac{I_0}{d^2} e^{-\sigma_t d} P(g,\theta) e^{-\sigma_t s} dx \end{aligned} \tag{2}$$

Fig. 1, (b) shows a rendering with estimated scattering parameters.

4 REFRACTIVE INDEX

We additionally need to estimate the refractive index of our acquired liquids for realistic rendering. For this purpose, we build on the work of Kim et al. [2017] to image ray deflections inside the glass and liquid volume by imaging gray code patterns projected by the LCD panel and observing their distortion. We first image the gray codes through an empty glass object and then repeat the process for the glass containing a liquid in order to isolate the distortion of light only due to the liquid volume. Finally, we employ inverse ray tracing given the known glass container shape to estimate the refractive index of the contained liquid. We found significant variation in the refractive index of various acquired liquids, e.g., ranging from $\eta = 1.35$ for chardonnay to $\eta = 1.47$ for olive oil.

5 ADDITIONAL RESULTS

(a) Olive oil (b) Whiskey (c) Cherry juice (d) Kiwi juice

Figure 3: Photograph and rendering comparisons for various acquired clear (a, b), and cloudy (c, d) translucent liquids.

Figure 3 presents rendering comparisons for a few acquired liquids against photographs of the liquids contained in a tall cocktail glass, backlit with uniform LCD panel illumination. As can be seen, our rendered results are a very good qualitative match to the photographs for both clear liquids exhibiting absorption (a, b) as well as cloudy liquids additionally exhibiting scattering (c, d). Here, the renderings have been generated using Mitsuba [Jakob 2010]. Additional examples are included in supplemental material. In conclusion, we have presented a much more natural and practical approach for estimating optical properties of everyday liquids compared to previous work, which is well suited for realistic rendering applications.

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