# Practical acquisition of translucent liquids using polarized transmission imaging

Imperial College London

30 JULY – 3 AUGUST Los Angeles SIGGRAPH2017

EPSRC Engineering and Physical Sciences Research Council

Jaewon Kim, Abhijeet Ghosh
Department of Computing, Imperial College London

A very simple “environment matting” like acquisition setup which consists of the target object placed between a camera and an LCD panel, as a polarized illumination source, for the efficient acquisition of physical properties of translucent liquids. Such physical properties enable realistic rendering of the liquids as shown below.

Figure 1. Rendering of clear (left) and cloudy (right) liquids with two frontal area light sources

Figure 2. Rendering of translucent liquids under Eucalyptus Grove (left) and an indoor scene (right)

(a) Rose (b) Rose (c) Olive oil (d) Whiskey (e) Chardonnay (f) Rose (g) Sesame oil (h) Cherry juice (i) Kiwi juice

Figure 3. Photograph and rendering comparisons for various acquired clear (a, b, c, d, e, f), and cloudy (g, h, i) translucent liquids

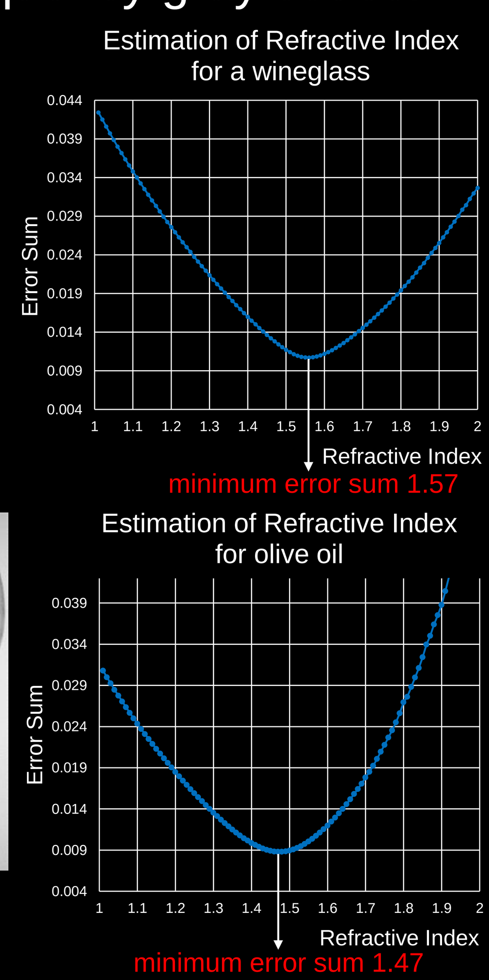
## 1. INTRODUCTION

We present a novel, practical method for acquisition of optical properties of common everyday translucent liquids using a simple acquisition setup. we build upon our recent work [Kim et al. 2017] which incorporates 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. We propose a 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 3. demonstrates renderings of various acquired translucent liquids with our proposed method separated into two types: those exhibiting only absorption (left), and those that exhibit both absorption and scattering (right).

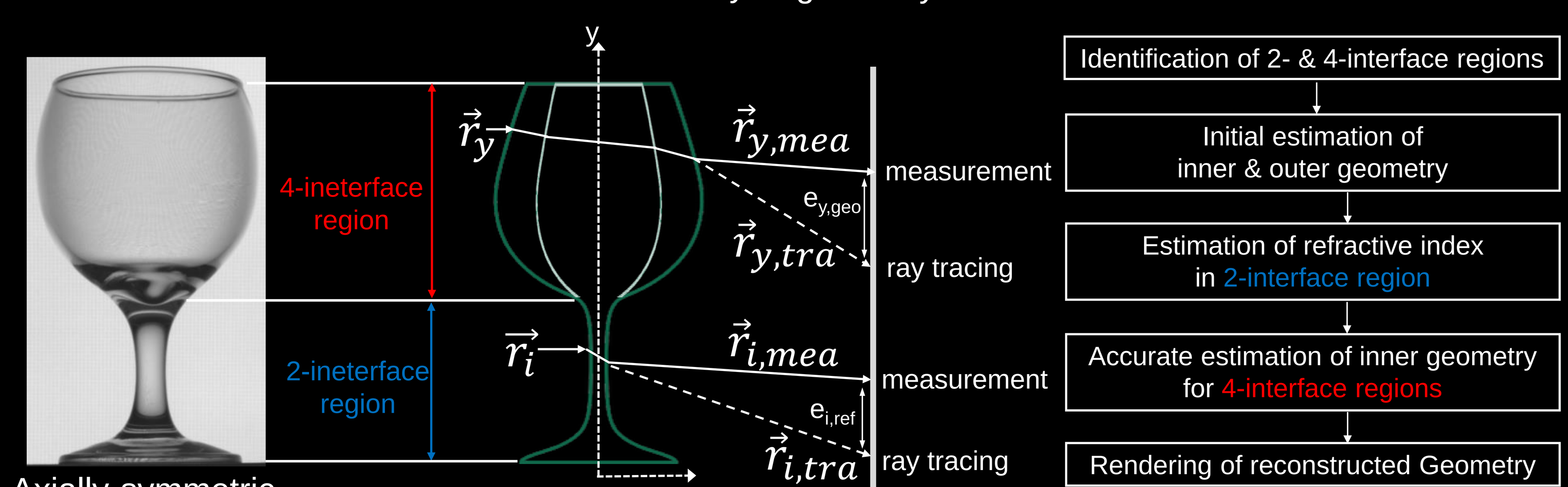
## 2. ACQUISITION AND PROCESSING

Our recent work [Kim et al. 2017] employed linear gradients to compute screen coordinates for camera rays and refine the position estimate using high frequency gray codes. We employed the horizontal gradients later in our pipeline for inner shape estimation. This results in a capture sequence of 13 patterns from a single viewpoint - one constant white screen illumination, four patterns consisting of X and Y linear gradients and their inverses, and four patterns each of the X and Y high frequency gray codes.


Sample photographs taken with gradient and gray code patterns




Def. vector Def. amp Flip image Enhanced boundary Approximated geometry Rendering result




Axially-symmetric transparent object

< Algorithm Pipeline >

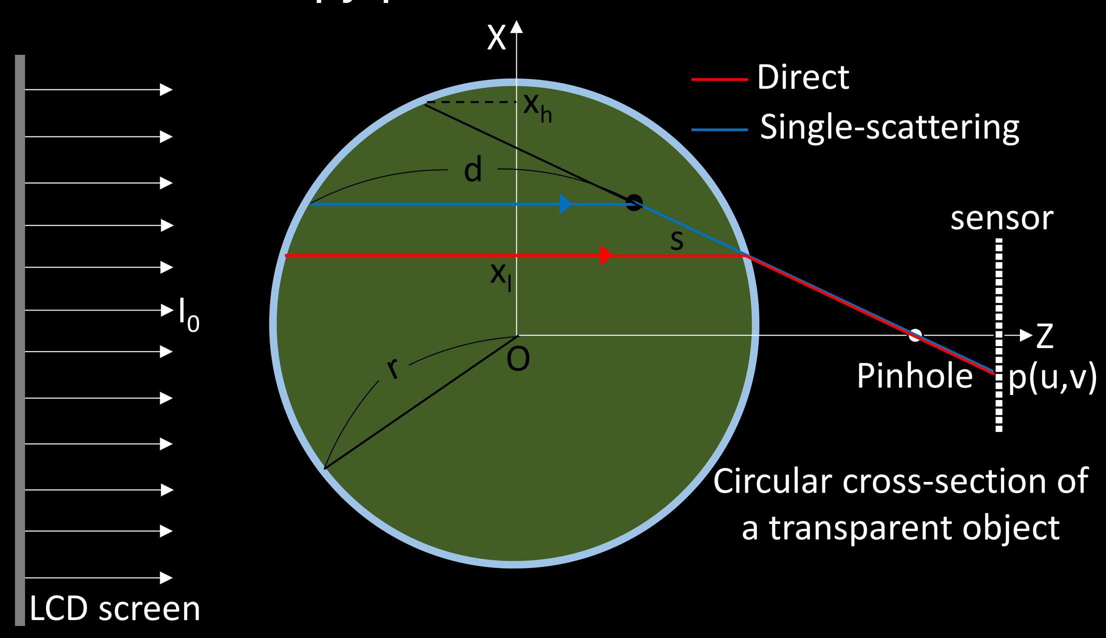
| | Refractive Index Estimation | Inner Geometry Estimation |
|---|---|---|
| Assumption | Uniform refractive index | Rotational symmetry |
| The known | Outer geometry, measured deflection | Refractive Index, measured deflection |
| Solution | $\arg\min_{n} \sum_{i\in[x,y]} \lvert \vec{r}_{i,mea} - \vec{r}_{i,tra} \rvert$ | $\arg\min_{r_y} \sum_{y} \lvert \vec{r}_{y,mea} - \vec{r}_{y,tra} \rvert$ |

Rendering of acquired transparent objects

## 3. ESTIMATION OF ABSORPTION AND SCATTERING

We estimate absorption coefficient of a clear liquid by applying Beer’s Law over a reference, glass-only, and liquid photographs. To estimate scattering coefficient of a translucent liquid, we modeled a ray propagation in direct and scattering components through a circular cross-section and induced equations incorporating extinction and scattering coefficients and anisotropy parameter.

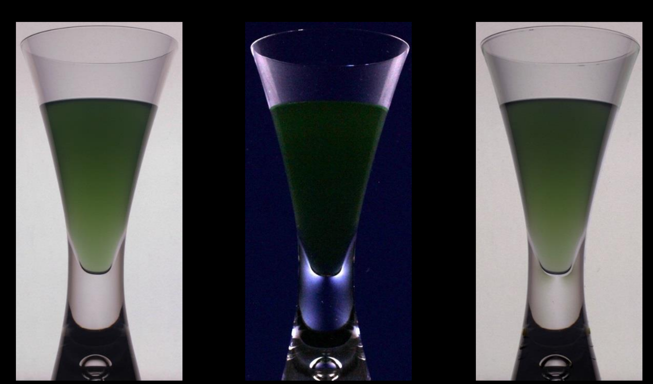
Ref. ($I_r$) Glass-only ($I_g$) Liquid ($I_l$)




< Absorption coefficient >

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

where $d_l(u,v)$ is the distance of light transport through the liquid volume for a camera ray (u,v)



Parallel pol. Cross pol.×5 Subtraction

< Scattering coefficient >

$$E_{direct}(u,v) = \frac{I_0}{4(r^2 - x_l{}^2)} e^{-2\sigma_t\sqrt{r^2 - x_l{}^2}}$$

$$E_{single}(u,v) = \beta \int_{x_l}^{x_h} \frac{I_0}{d^2} e^{-\sigma_t d} P(g,\theta) e^{-\sigma_t s} dx$$

where $\sigma_t$, β, and g indicate extinction and scattering coefficient and anisotropy parameter.

unit: $10^{-2}$ $mm^{-1}$

| Cloudy liquids | Extinction coefficient | | | Scattering coefficient | | | scattering anisotropy (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| | R | G | B | R | G | B | R | G | B |
| Merlot wine | 0.7482 | 1.7863 | 1.9655 | 0.0068 | 0.0005 | 0.0002 | 0.9334 | 0.9418 | 0.9486 |
| Sesame Oil | 0.7243 | 1.3567 | 1.6605 | 0.0302 | 0.0245 | 0.0173 | 0.9642 | 0.9713 | 0.9836 |
| Cherry juice | 0.2906 | 0.8313 | 0.7683 | 0.0102 | 0.0163 | 0.0185 | 0.9521 | 0.9485 | 0.9643 |
| Kiwi juice | 0.6093 | 0.5017 | 1.1413 | 0.0111 | 0.0117 | 0.0111 | 0.9784 | 0.9685 | 0.9964 |
| Coffee | 0.3741 | 0.5089 | 0.7724 | 0.2063 | 0.1875 | 0.1109 | 0.9123 | 0.9045 | 0.9163 |
| Apple juice | 0.1902 | 0.6967 | 1.5837 | 0.0325 | 0.0297 | 0.0177 | 0.9189 | 0.9215 | 0.9313 |
| Cocktail | 0.4802 | 0.9539 | 1.6219 | 0.0091 | 0.0081 | 0.0052 | 0.9313 | 0.9432 | 0.9426 |
| Mango juice | 0.2552 | 0.7285 | 1.7122 | 0.0159 | 0.0150 | 0.0088 | 0.9256 | 0.9135 | 0.9244 |

## 4. ESTIMATION OF REFRACTIVE INDEX

We build on our recent work [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 1.35 for chardonnay to 1.47 for olive oil.

## ACKNOWLEDGEMENTS

This work was supported by an EPSRC Early Career Fellowship EP/N006259/1 and Royal Society Wolfson Research Merit Award.

## REFERENCES

[1] W. Jakob. 2010. Mitsuba Physically Based Renderer. (2010). http://www.mitsuba-renderer.org/index.html.

[2] J. Kim, I. Reshetouski, and A. Ghosh. 2017. Acquiring axially-symmetric transparent objects using single-view transmission imaging. 30th IEEE Conference on Computer Vision and Pattern Recognition (CVPR) (2017).

[3] S. G. Narasimhan, M. Gupta, C. Donner, R. Ramamoorthi, S. K. Nayar, and H. W. Jensen. 2006. Acquiring Scattering Properties of Participating Media by Dilution. ACM Trans. Graphics (Proc. SIGGRAPH) (2006), 1003–1012.