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Recovering Inner Slices of Translucent Objects by Multi-frequency Illumination

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Translucent objects have complex appearance. It is a superposition of light rays emitted from inner slices at every depths, blurred by subsurface scattering. Because visualizing internal structure of objects is of broad interest in medical and art analyses and industry inspection, various imaging techniques have been developed in the past. In particular, since the translucency effect becomes significant for many materials in near infrared (NIR) wavelengths, infrared photography is used as one of common techniques for achieving this goal. For example, it is used for observing inner layers of oil paintings that tell us the drawing technique, growth, history, and/or authenticity of old age painters.

One of the major challenges in observing inner layers of translucent objects is to separate inner appearances with properly dealing with scattering. When an image of a translucent layered object is recorded, the observed intensity can be modeled as a summation of the appearance of multiple depth layers as illustrated in Fig. 1 (a). The observed intensity $L_o(c)$ at camera pixel c can be expressed by

$$L_o(c) = \sum_d S_d(c), \tag{1}$$

where S_d is an appearance slice of the layer at depth d. The appearance slice S_d is generally blurry due to the scattering effect inside the medium as illustrated in Fig. 1 (b). By denoting h_d as a depth-dependent PSF at depth d, the observation L_o can be re-written as

$$L_o(c) = \sum_d (R_d * h_d)(c), \tag{2}$$

where R_d is the sharp slice that we are interested in estimating, which we call a radiance slice, and $*$ denotes a convolution operator. Our goal is to recover radiance slices R_d from the composite observation L_o.

To achieve this goal, we develop a *multi-frequency illumination* measurement method, which can recover sharp appearance of inner slices at a desired depth with explicitly removing scattering blur. It is built upon the high-frequency illumination (HFI) method proposed by Nayar *et al.* [1], using depth-dependent low-pass characteristics. Specifically, our method uses a spatial pattern projection with varying the pattern pitch as illustrated in Fig. 2 (a). Our multi-frequency illumination method allows us to separate direct (high-frequency) and global (low-frequency) components as in [1], yet at various frequency levels that define high- and low-frequencies.

The HFI method separates direct and global components by projecting small pitch checker patterns. In our case, we model the direct component $D(p,c)$ under HFI with pattern pitch p as

$$D(p,c) = \sum_d \alpha(h_d, p) R_d(c), \tag{3}$$

where $\alpha(h_d, p)$ is a relative brightness of $D_d(p,c)$ to $R_d(c)$. A set of direct component images $D(p,c)$ taken under the multi-frequency illumination of m pitch variations can be written in a matrix form as

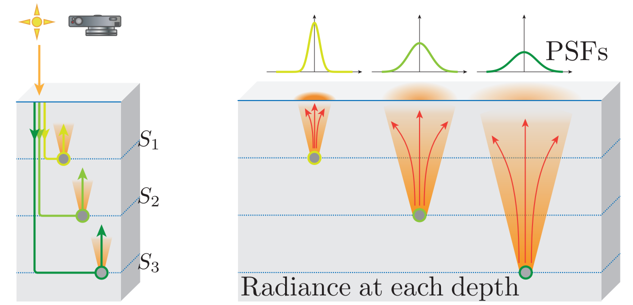
$$\mathbf{D}(c) = \mathbf{A}\mathbf{R}(c). \tag{4}$$

Here, $\mathbf{D}$ is a vector of direct components measured under m variations of the pattern pitches at pixel c, $\mathbf{R}$ is a vector of n layers of radiance slices, and $\mathbf{A}$ is a matrix containing direct component ratios computed from the projected pattern pitch and the depth-dependent PSF. We estimate the optimal matrix $\tilde{\mathbf{A}}$ and recover radiance slices via least-square as

$$\mathbf{R}(c) = \tilde{\mathbf{A}}^{+}\mathbf{D}(c). \tag{5}$$

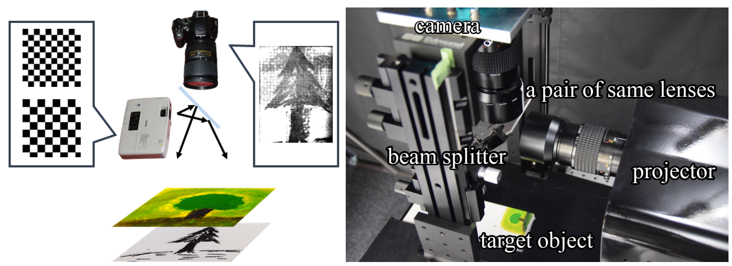
We implement the system as shown in Fig. 2 (b) and the result is summarized in Fig. 3. We can see the texture of the spiny tree of the draft (inner) layer is clearly observed.

This is an extended abstract. The full paper is available at the Computer Vision Foundation webpage.



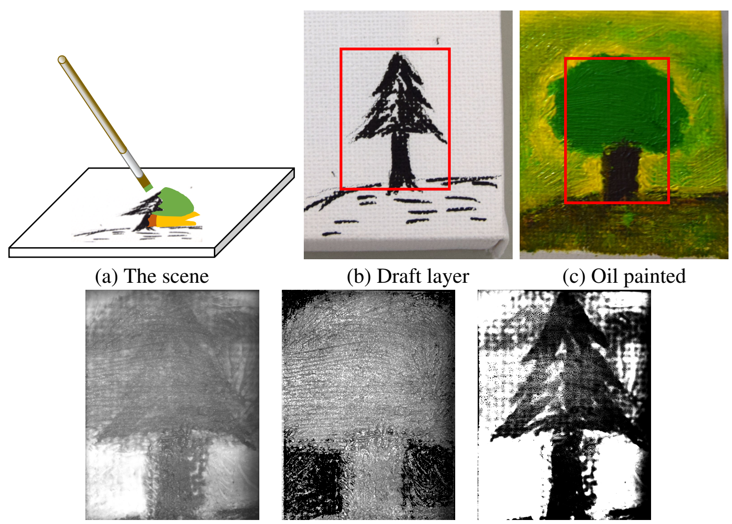
(a) (b)

Figure 1: Appearance of translucent objects. (a) Captured image contains all components from each depth. (b) Lights spread depending on the depth.



(a) (b)

Figure 2: (a) Illustration of our multi-frequency illumination method. Patterns of multiple frequencies are projected, and desired slices are recovered. (b) Implementation of measurement system.



(a) The scene (b) Draft layer (c) Oil painted

(d) NIR photo (e) Ours (surface slice) (f) Ours (inner slice)

Figure 3: Experimental result of oil painting scene. (a) Target scene. We draw a colored round tree on top of the draft of spiny tree. (b) Draft (inner) layer of the painting. (c) Outer layer. (d) NIR photography. (e, f) Our result. Textures of inner and outer layers are clearly seen.

[1] S. K. Nayar, G. Krishnan, M. D. Grossberg, and R. Raskar. Fast separation of direct and global components of a scene using high frequency illumination. In *Proc. SIGGRAPH*, pages 935–944, 2006.