A Fixed Viewpoint Approach for Dense Reconstruction of Transparent Objects

Kai Han[1], Kwan-Yee K. Wong[1], Miaomiao Liu[2]
[1]The University of Hong Kong, Hong Kong. [2]NICTA and CECS, ANU, Canberra.

This paper addresses the problem of reconstructing the surface shape of transparent objects. The difficulty of this problem originates from the viewpoint dependent appearance of a transparent object, which quickly makes reconstruction methods tailored for diffuse surfaces fail disgracefully. Existing solutions (e.g., [1, 2]) for surface reconstruction of transparent objects often work only under restrictive assumptions and special hardware setups, or for a particular class of objects. There exists no general solution to this challenging and open problem.

In this paper, we develop a fixed viewpoint approach for dense surface reconstruction of transparent objects based on altering and triangulating the incident light paths before light rays enter the object. We present a simple setup that allows us alter the incident light paths by means of refraction of light. Under this proposed setup, the segment of a light path between the first entry point (FEP) on the object surface and the optical center of the camera (referred to as path after contact (PAC)) remains fixed. This allows us ignore the details of the complex interactions of light inside the object. Compared with existing methods, our proposed approach (1) assumes neither a known nor homogeneous refractive index of the object; (2) places no restriction on the exact number of refractions and reflections taken place along a light path; (3) assumes no parametric form for the shape of the object. This allows our approach to handle transparent objects with a complex structure. Besides, our proposed setup is also very simple, and does not depend on any special and expensive hardware.

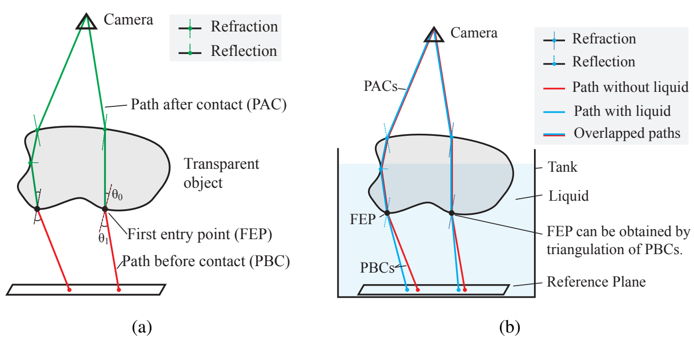

Figure 1: (a) A light path through an object is partitioned into two parts, namely i) the *path before contact* (PBC) which originates from the reference pattern to the *first entry point* (FEP) on the object surface (i.e., the red paths) and ii) the *path after contact* (PAC) that originates from FEP, passes through the interior of the object and terminates at the optical center of the camera (i.e., the green paths). (b) The first entry point can be recovered by filling the tank with a liquid to alter the PBC and triangulating the two PBCs.

In our proposed setup (see Figure 1), a camera is used to capture images of a transparent object in front of a reference pattern. The camera and the object are kept fixed with respect to each other. This will ensure the PACs remain unchanged for all the image points of the object. The reference pattern is used here to reconstruct the paths before contact (PBCs), and is placed in two distinct positions. As mentioned before, our approach is based on altering the PBCs. To achieve this, we employ a water tank to immerse part of the object surface into a liquid so as to alter the PBCs by means of refraction of light. Two images of the transparent object are acquired for each position of the reference pattern, one without liquid in the tank and one with liquid in the tank. By establishing correspondences between image points of the object and points on the reference pattern, we can construct two PBCs for each image point, one in air and one in the liquid respectively. The FEP can then be recovered by triangulating these two PBCs. If the refractive index of the liquid is known a priori, our method can also recover the surface normal at each reconstructed surface point.

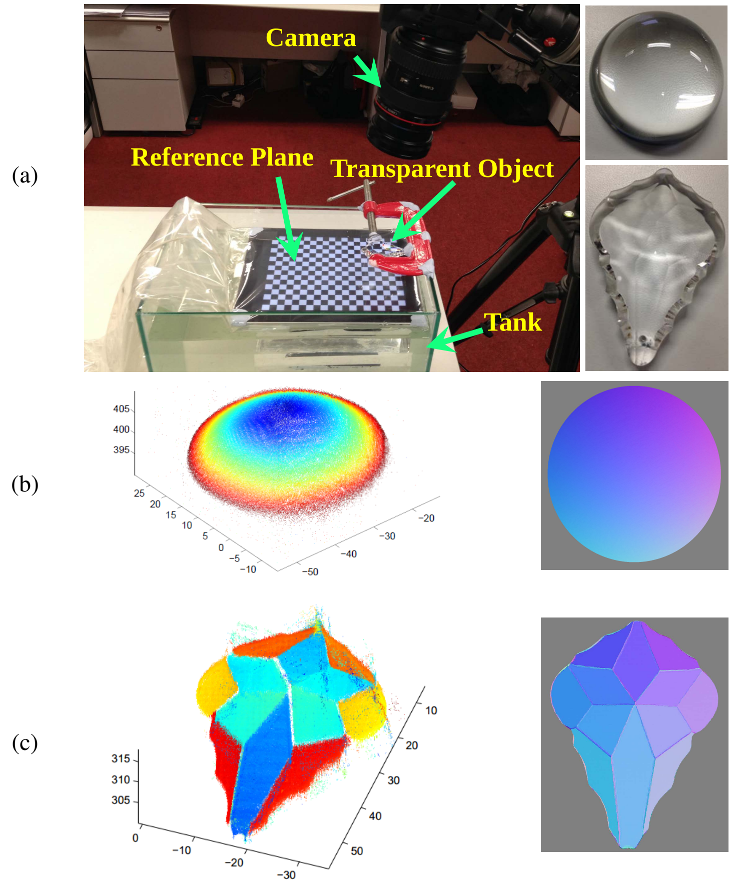

Figure 2: (a) Real experiment setup and reconstruction samples, namely a smooth glass *hemisphere* and a diamond-shape *ornament* with piecewise planar surfaces. (b) *Hemisphere* reconstruction results. (c) *Ornament* reconstruction results. The first column shows the reconstructed FEPs and the second column shows the reconstructed normal map.

To evaluate the accuracy of our approach on real data, we performed experiments on a smooth glass *hemisphere*, and a diamond-shape *ornament* with piecewise planar surfaces (see Figure 2). Since no ground truth was available, a sphere was fitted from the FEP cloud to evaluate the reconstruction accuracy for the *hemisphere*. We compare the fitted sphere radius with the measurement, which are 26.95 *mm* and 27.99 *mm* respectively. In order to evaluate the reconstruction of the *ornament*, we first used RANSAC to fit a plane for each facet.The reconstruction error for each facet was measured by the distances from the reconstructed FEPs to the fitted plane, as well as the angles between the reconstructed normals of the facet and the normal of the fitted facet. Details are included in the paper. Both the quantitative and qualitative results demonstrate the high reconstruction accuracy of our method.

[1] I. Ihrke, K. N. Kutulakos, H. P. A. Lensch, M. Magnor, and W. Heidrich. State of the art in transparent and specular object reconstruction. In *Eurographics STAR*, pages 87–108, 2008.

[2] I. Ihrke, K. N. Kutulakos, H. P. A. Lensch, M. Magnor, and W. Heidrich. Transparent and specular object reconstruction. *Computer Graphics Forum*, 29:2400–2426, 2010.

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