A Fixed Viewpoint Approach for Dense Reconstruction of Transparent Objects

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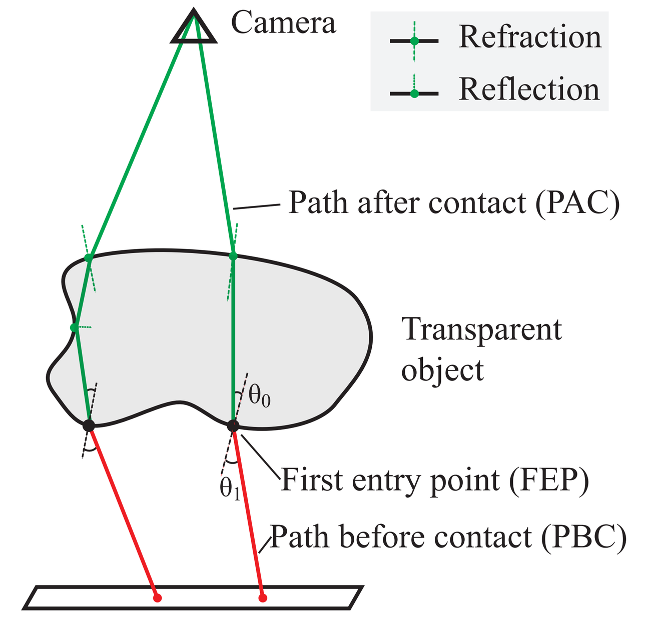
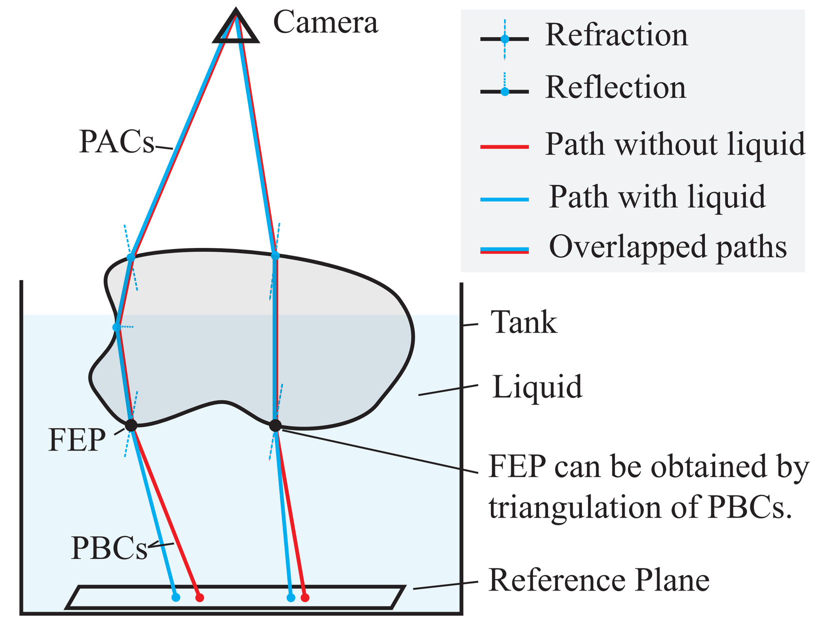
Problem Definition & Contribution

We are addressing the problem of dense reconstruction of transparent objects from a fixed viewpoint. In particular, we present a simple setup that allows us alter the incident light paths before light rays enter the object, and develop a method for recovering the surface by ray triangulation.

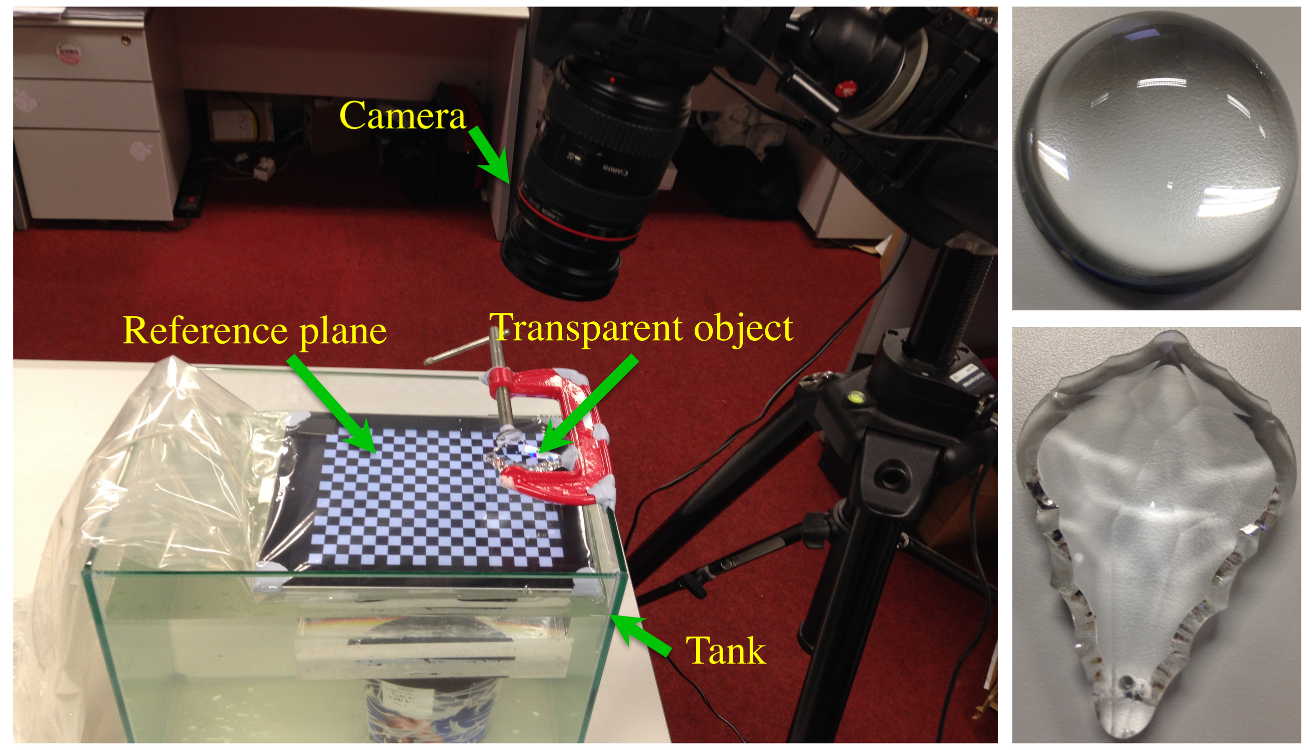




Compared with existing approaches, our proposed method has the following benefits:

- It does not assume any parametric form for the shape of a transparent object.
- It can handle a transparent object with a complex structure, with an unknown and even inhomogeneous refractive index.
- It considers only the incident light paths before light rays enter a transparent object, and makes no assumption on the exact number of refractions and reflections taken place as light travels through the object.
- The proposed setup is simple and inexpensive.

Setup

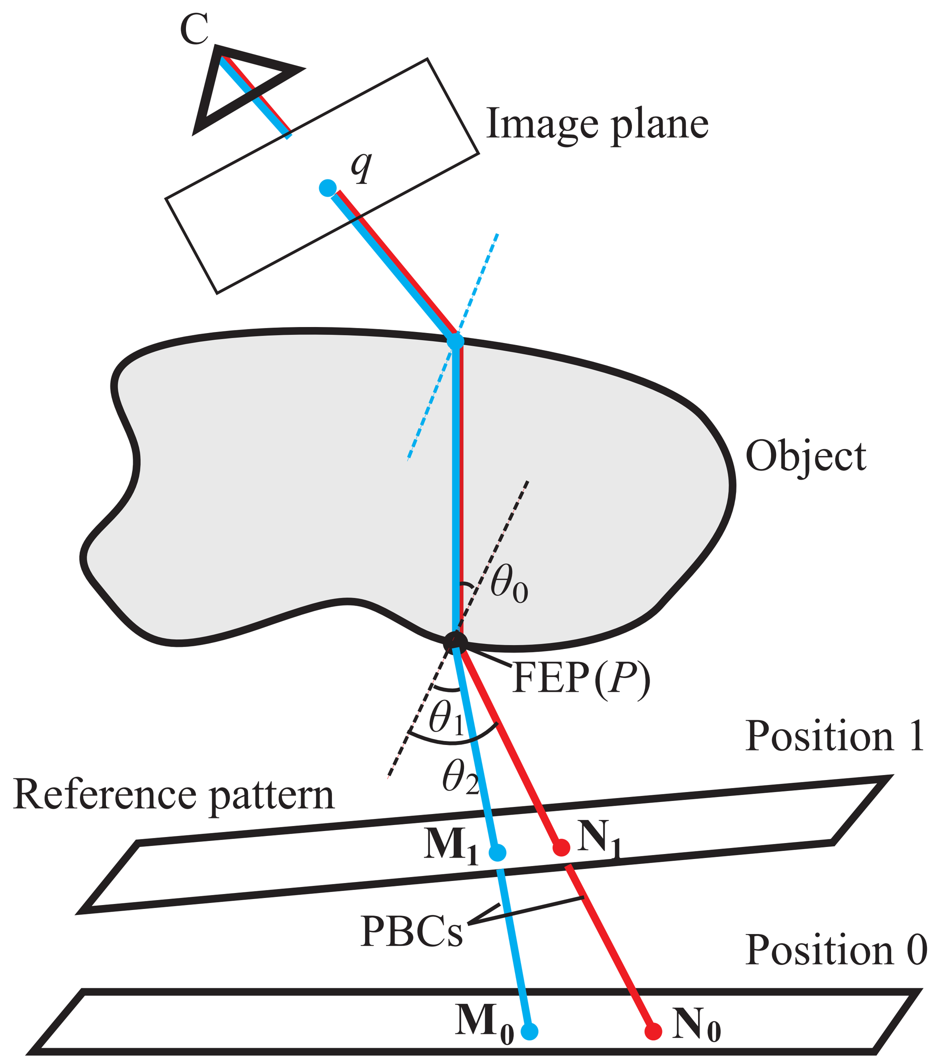


Dense Refraction Correspondences

We employ an iPad as a reference plane and capture an image sequence of a white line sweeping horizontally and then vertically on a black background on the iPad screen. For each image point, its correspondence on the reference plane can be established by identifying the image frame in which its intensity attains a peak value. Knowing the correspondences on two distinct reference plane positions allows the recovery of the PBC for that image point.

FEPs Reconstruction

Consider an image point q on the transparent object. Suppose $\mathbf{M_0}$ and $\mathbf{M_1}$ denote its correspondences on the reference plane under position 0 and position 1 with liquid in the tank, respectively. Similarly, let $\mathbf{N_0}$ and $\mathbf{N_1}$ denote its correspondences without liquid in the tank. We can construct two PBCs for q. The FEP can then be recovered as the point of intersection between the two PBCs. In practice, we seek $\mathbf{M_c}$ and $\mathbf{N_c}$, respectively, on these two PBCs such that their distance is minimum among all the points on these two PBCs. We take the mid-point between $\mathbf{M_c}$ and $\mathbf{N_c}$ as the FEP for q.



Surface Normal Recovery

Let $\Delta\theta = \cos^{-1}(\mathbf{U}\cdot\mathbf{V})$ denote the angle between the two PCBs, where $\mathbf{U}$ and $\mathbf{V}$ are unit vectors being parallel to $\mathbf{M_1M_0}$ and $\mathbf{N_1N_0}$, respectively. With known refractive indices λ_1 and λ_2 for the liquid and air, respectively, the incident angle θ_1 can be recovered by

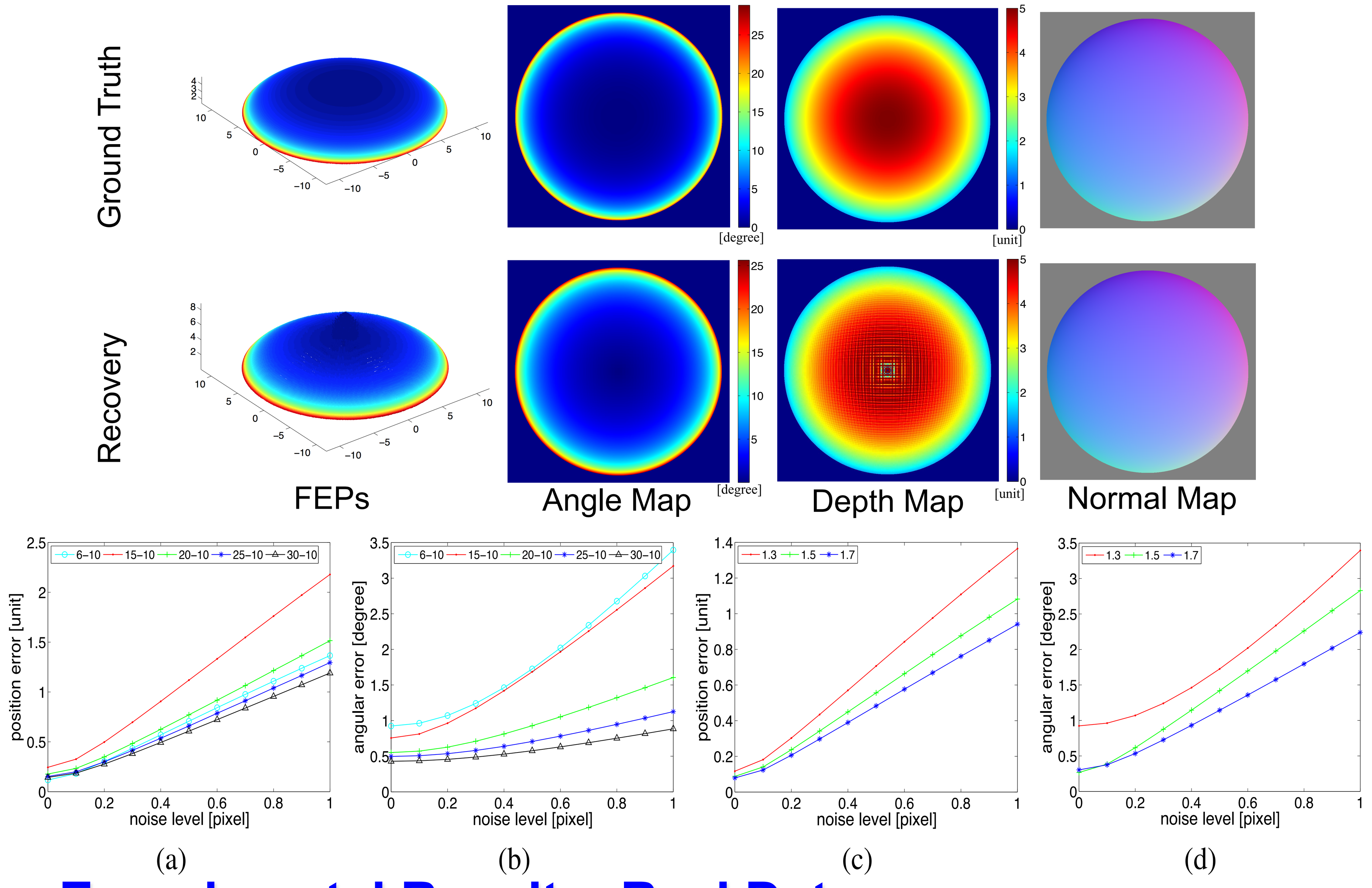
$$\theta_1 = \tan^{-1}((\lambda_2 \sin\Delta\theta)/(\lambda_1 - \lambda_2\cos\Delta\theta))$$

The surface normal $\mathbf{n}_p$ at P is then given by

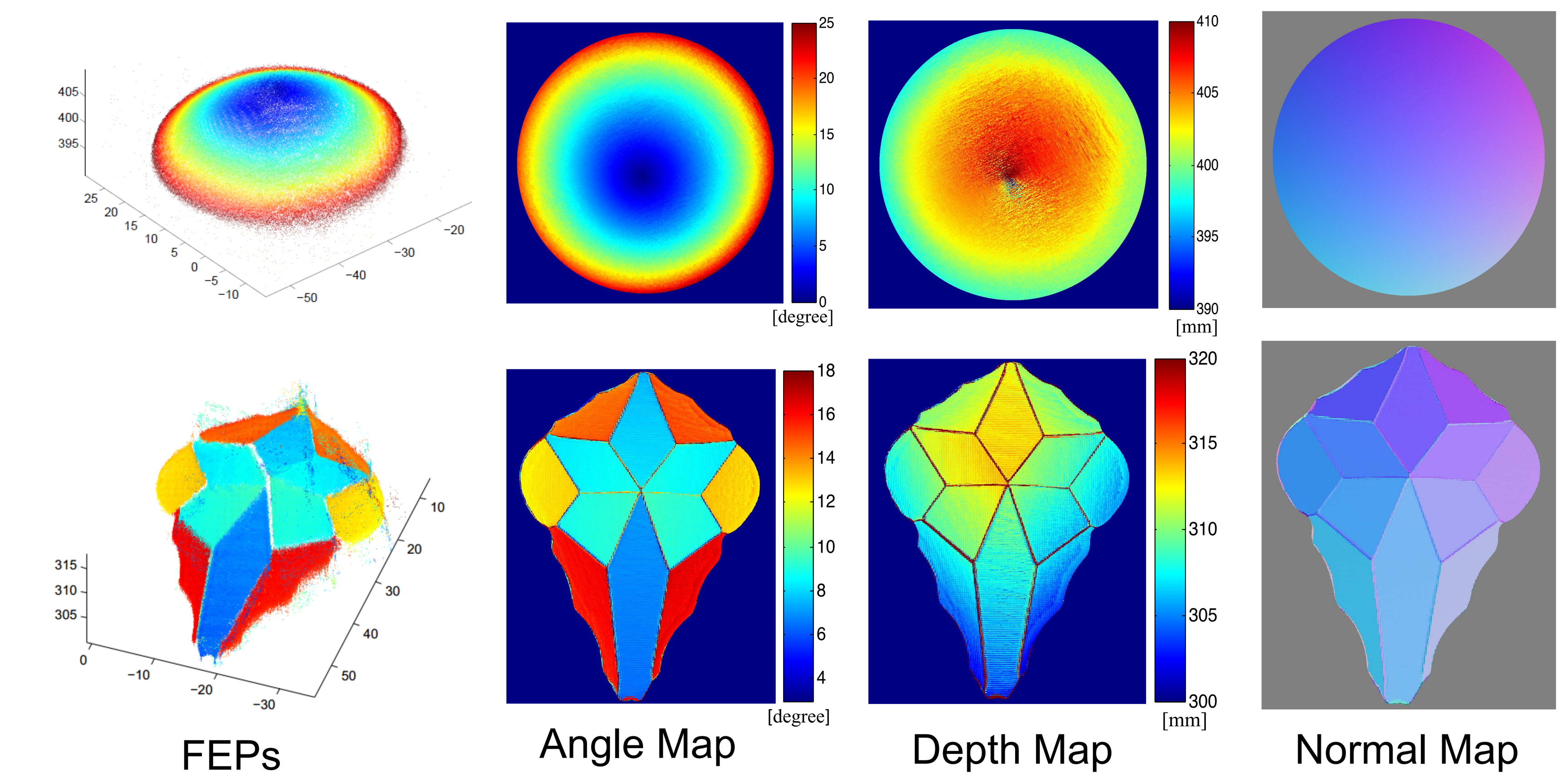
$$\mathbf{n}_p = \mathbf{R}(\theta_1, \mathbf{V}\times\mathbf{U})\mathbf{U}$$

where $\mathbf{R}(\theta, \mathbf{a})$ denotes a Rodrigues rotation matrix for rotating about the axis $\mathbf{a}$ by angle θ.

Experimental Results: Synthetic Data



Experimental Results: Real Data



	Mean FEPs error (mm)	Mean normal error (degree)
hemisphere	0.59	6.97
ornament	0.73	7.34