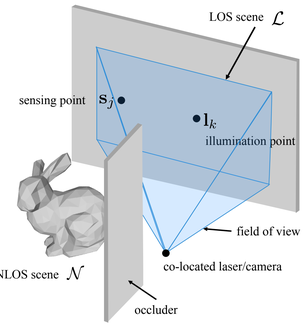
The Geometry of First-Returning Photons for Non-Line-of-Sight Imaging

Chia-Yin Tsai†, Kiriakos N. Kutulakos‡, Srinivasa G. Narasimhan†, Aswin C. Sankaranarayanan†

†Carnegie Mellon University ‡University of Toronto

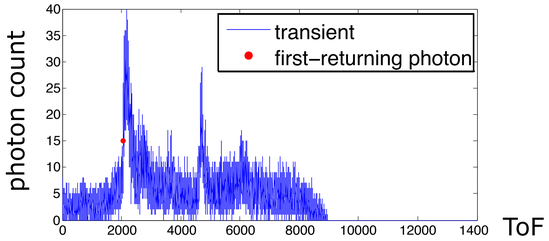
None-line-of-sight imaging



NLOS imaging uses properties measured in LOS to infer the properties of the NLOS scene. In particular, prior works [1,2] use the path length associated with three-bounce light paths to create ellipsoidal constraints of the NLOS scene.

First-returning photons

We provide a formulation for NLOS shape recovery using the path length associated with first-returning photons.

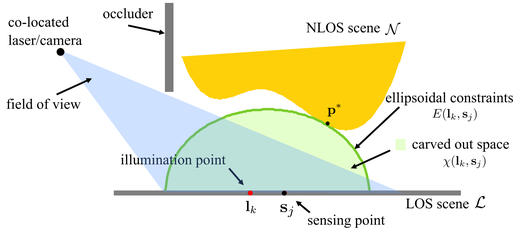


Advantages of a framework that uses first-returning photons:

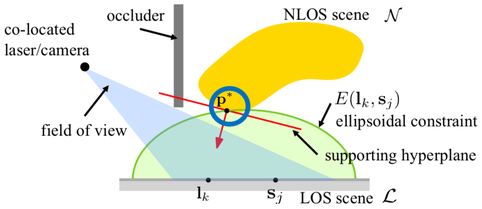
1. Given the illumination and sensing points, the NLOS scene point contributing to the first-returning photon is **unique** in most setups.
2. Rely on the ToF only and does not require accurate intensity measurement. Thus the proposed method is robust to different NLOS reflectance.
3. New opportunities for sensing requirements.

Geometry of first-returning photons

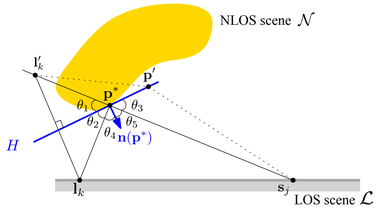
Observation 1. There are no NLOS scene points in the interior of the ellipsoidal constraint.



Observation 2. Suppose the NLOS scene is locally smooth at $\mathbf{p}^*$, the unique supporting hyperplane at $\mathbf{p}^*$ is tangential to the ellipsoid.

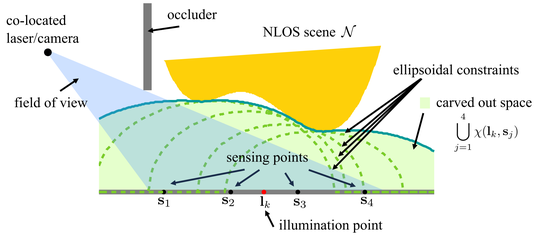


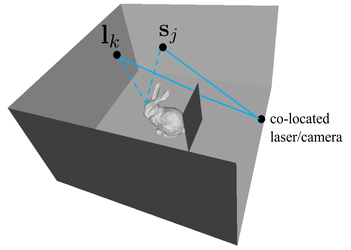
Observation 3. Under local smoothness of the NLOS scene at $\mathbf{p}^*$, the surface normal $\mathbf{n}(\mathbf{p}^*)$ is the angular bisector of the vector from $\mathbf{p}^*$ to the illumination and sensing spot, respectively.



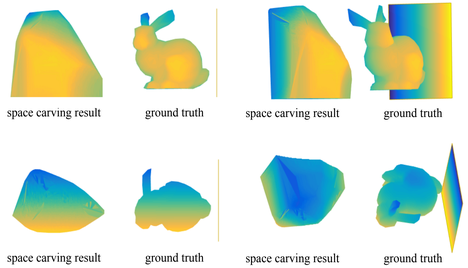
Algorithms and Experiments

Space carving for NLOS imaging

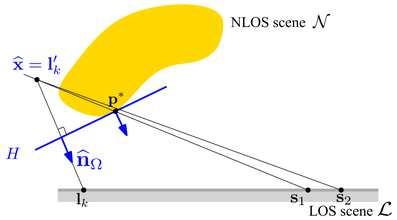




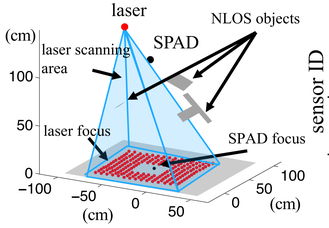
acquisition setup



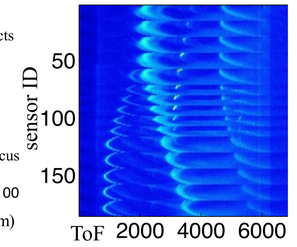
Shape recovery using planar assumption



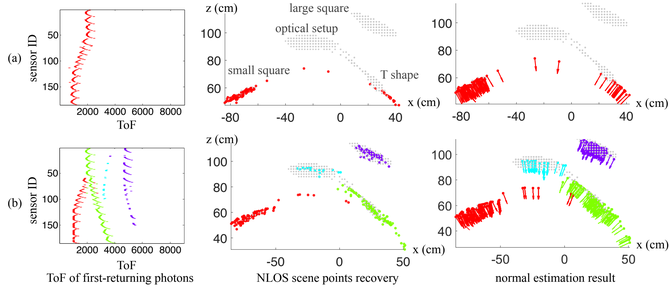
Real data collected in [2]



acquisition setup



light transient measured by SPAD



References

1. A. Velten, T.Willwacher, O. Gupta, A. Veeraraghavan, M. G. Bawendi, and R. Raskar. Recovering three-dimensional shape around a corner using ultrafast time-of-flight imaging. Nature Comm., 3:745 – 758, 2012.
2. M. Buttafava, J. Zeman, A. Tosi, K. Eliceiri, and A. Velten. Non-line-of-sight imaging using a time-gated single photon avalanche diode. Optics Express, 23(16):20997–21011, 2015.