Exploiting Light Field Spectra for Passive NLoS Imaging

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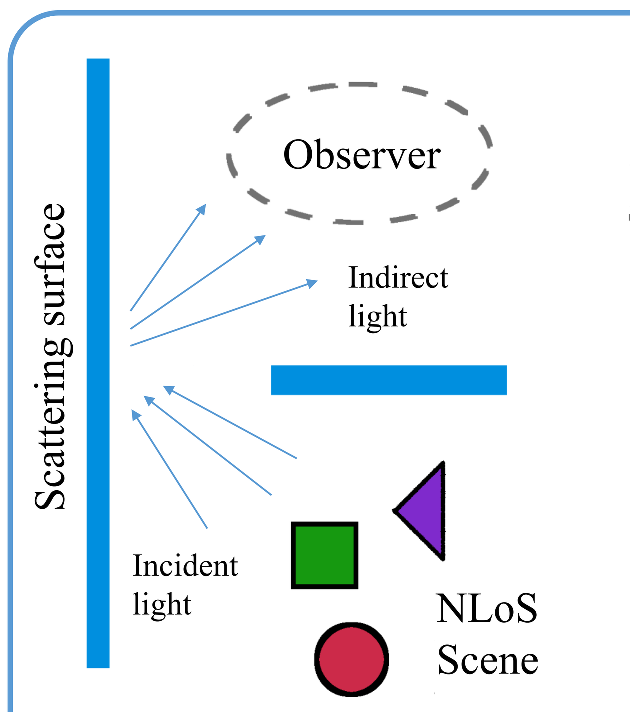
Overview



Passive NLoS imaging setup

Results: Performed data fusion of RGB light field spectra to image a non-line-of-sight (NLoS) object and showed improvements over existing techniques

Methodology

- Low-level data fusion of light field spectra
- Solving inverse problem with knowledge of object's scattering properties and occluder location
- Light fields captured with camera on rotation arm

Differential Field-of-View (DFoV) Model

- We take the differential of observer's light field w.r.t. spatial position on scattering surface (vantages) to exploit changes in incident NLoS scene
- Then we project differential onto constraint to suppress clutter (violations of assumptions) and noise

Single-Bounce Light Field Model
Scattered angular radiance from single vantage

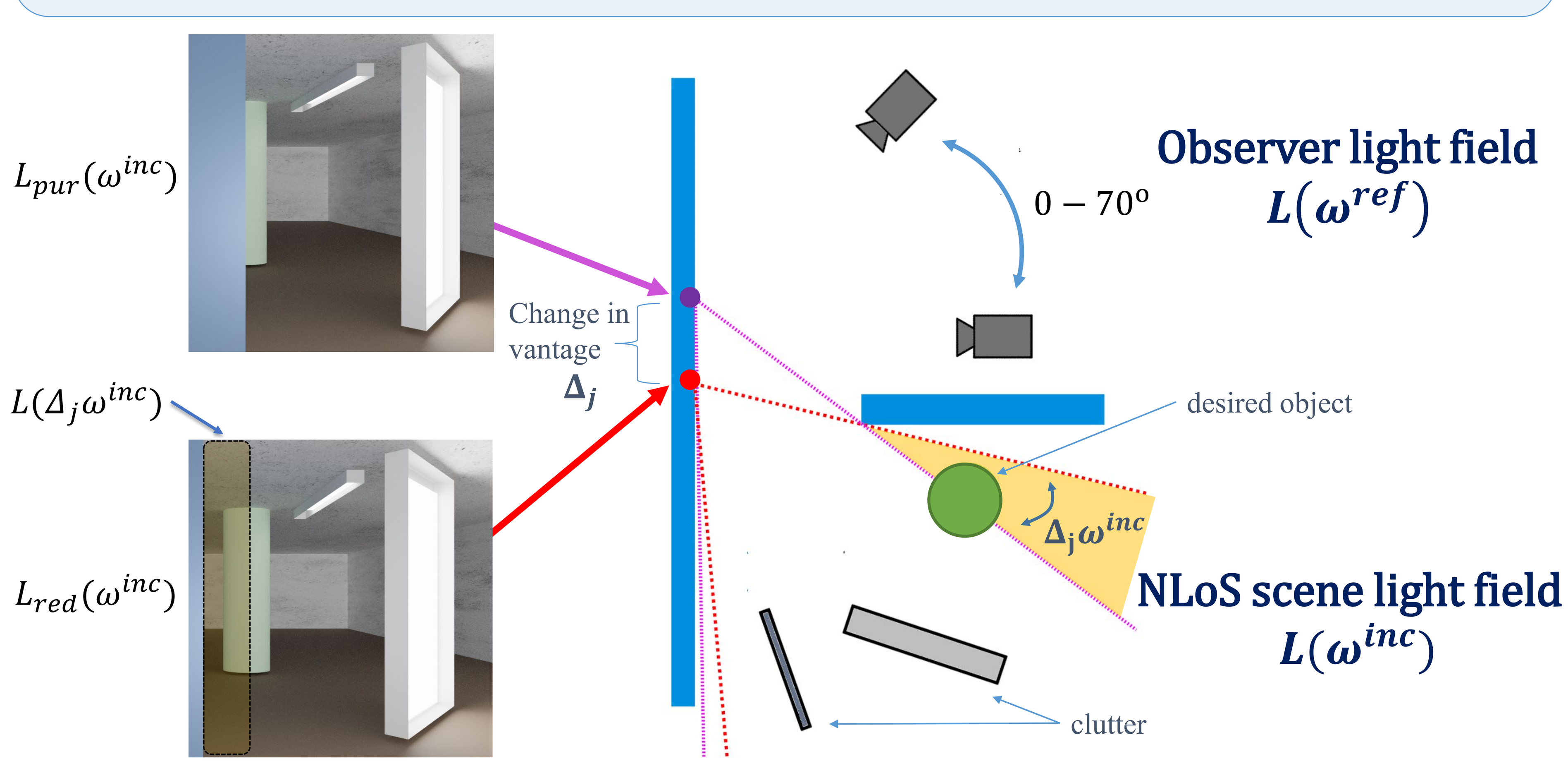
$$L(\omega^{ref}) = \int_{\Omega^{inc}} L(\omega^{inc}) f(\omega^{inc}, \omega^{ref}) \cos\omega^{ref}\, d\omega^{inc}$$

Observer light field (radiance); Bidirectional reflectance distribution function (BRDF); Scene's light field (radiance)

DFoV Projection onto Constraint
Utilizing differences in views from different vantages

$$L(\Delta_j\omega^{inc}) \approx \frac{\vec{x}\cdot\vec{\beta_j^*}}{\left\|\vec{\beta_j^*}\right\|_2^2} \quad \text{where} \quad \vec{x} = \frac{dL(w^{ref})}{d\Delta_j}$$

Increment of scene's w.r.t. vantage; Differential of observer's w.r.t. vantage; Constraint by vantage change and BRDF

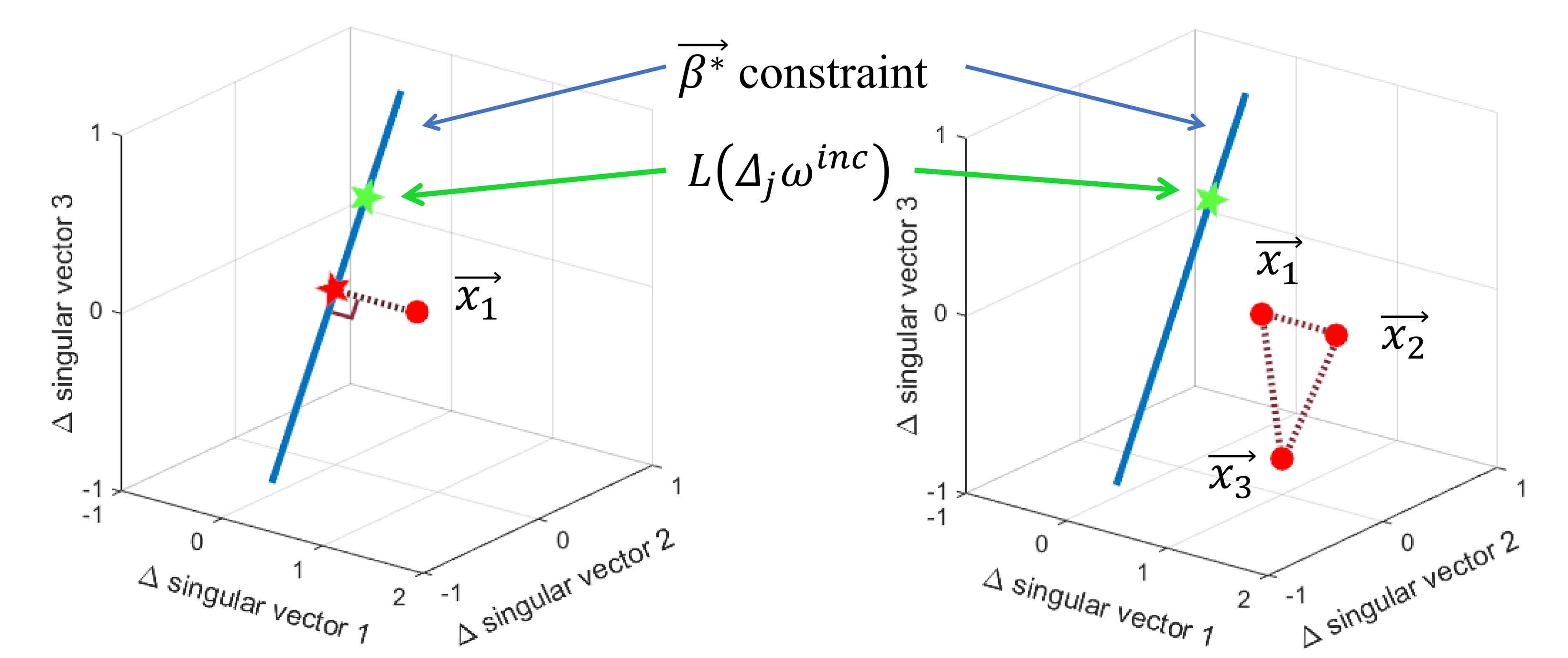


Changes in views from different vantages due to wall obstruction

Passive NLoS imaging using different vantages (red and purple) to image object (green) in presence of clutter (gray)

Multi-Spectra DFoV Model

- Create multi-spectra model to improve loss in projection in DFoV settings



Projection onto $\vec{\beta^*}$ using a single spectrum $\vec{x_1}$ leads to loss of accuracy in $L(\Delta_j\omega^{inc})$

Goal is to extract $L(\Delta_j\omega^{inc})$ using multi-spectra light fields $\vec{x_n}$ together

Modeling the Spectrum Measurements

- Model $\vec{x}$ as composition of desired object plus contribution of clutter objects
- Doing so enables us to exploit complementary information between each spectrum
- Take N as total number of light field spectra, K as number of clutter objects

$$\vec{x_n} = L^*\vec{\beta^*} + c_{n,1}\vec{\beta_1} + c_{n,2}\vec{\beta_2} + \cdots + c_{n,K}\vec{\beta_K}$$

$\{\vec{x_n}\}_{n=1}^N$ – differential spectrum light fields from vantage **(measurements)**
L^* – intensity of NLoS object **(goal)**
$\vec{\beta^*}$ – constraint at vantage
$\{c_{n,k}\}_{n=1,k=1}^{N,K}$ – intensities of clutter for each spectrum
$\{\vec{\beta_k}\}_{k=1}^K$ – clutter element **(noise)**

Constructing Convex Optimization Problem

- Since we assumed L^* is identical, can eliminate $L^*\vec{\beta^*}$ by taking differences between light fields

$$\vec{v_{N-1}} = \vec{x_N} - \vec{x_1} = (c_{N,1} - c_{1,1})\vec{\beta_1} + (c_{N,2} - c_{1,2})\vec{\beta_2} + \cdots + (c_{N,K} - c_{1,K})\vec{\beta_K}$$

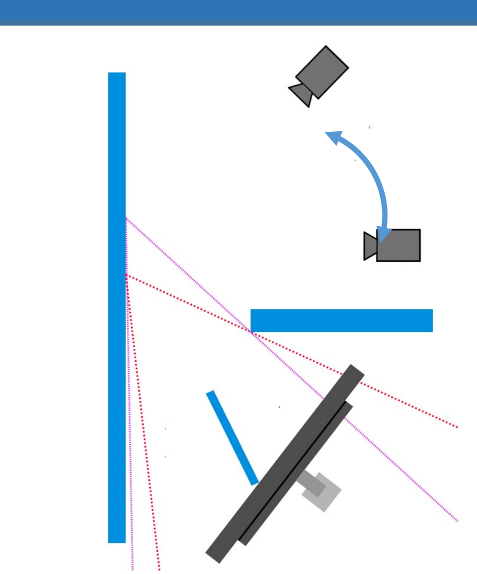
- Take $A = [\vec{v_1}|\vec{v_2}|\cdots|\vec{v_{N-1}}]$, so span of A is span of all possible clutter light fields
- Can solve for L^* as closest points between set of constraint line and all clutter combinations

$$\begin{aligned} \underset{u,y}{\text{minimize}} \quad & \tfrac{1}{2}\|\vec{u} - \vec{y}\|_2^2 \\ \text{subject to} \quad & \{A\vec{s} + \vec{x_1} = \vec{u} \text{ for some } \vec{s} \in \mathbb{R}^{N-1}\} \\ & \{z\vec{\beta^*} = \vec{y} \text{ for some } z \in \mathbb{R}\} \end{aligned}$$

$A\vec{s}$ – all clutter light fields $\vec{x_1}$ – any spectrum light field $z\vec{\beta^*}$ – values on constraint line

- Can transform to quadratic program with an analytical solution

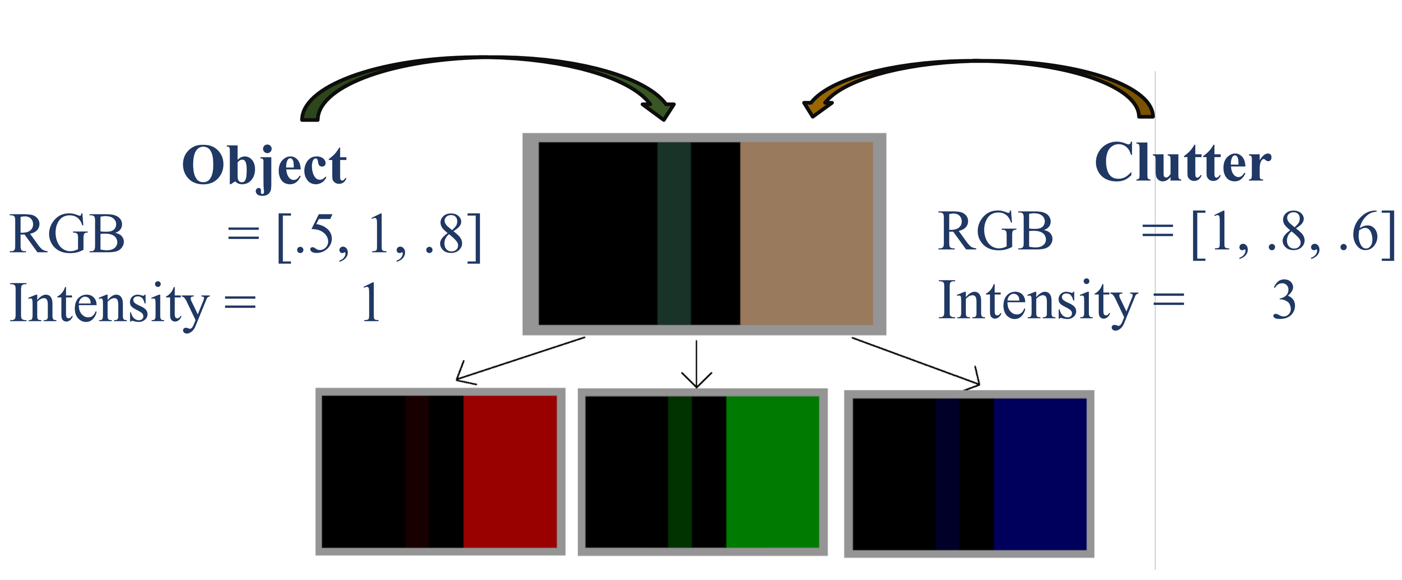
Multi-Spectra DFoV Experimental Verification



Experimental setup with LCD screen and clutter occluder

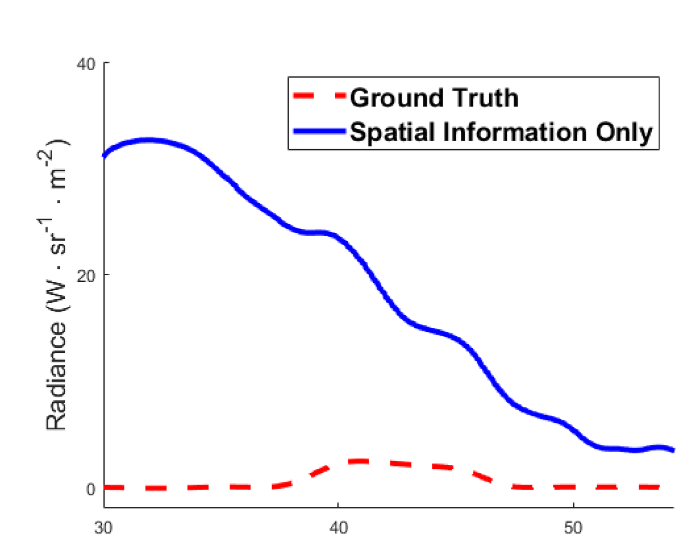
Setup

- LCD simulates scene with RGB spectra
- Can turn on RGB pixels independently to measure three light field spectra $\vec{x_n}$
- Simulate clutter with another occluding wall that creates a differential on scatterer

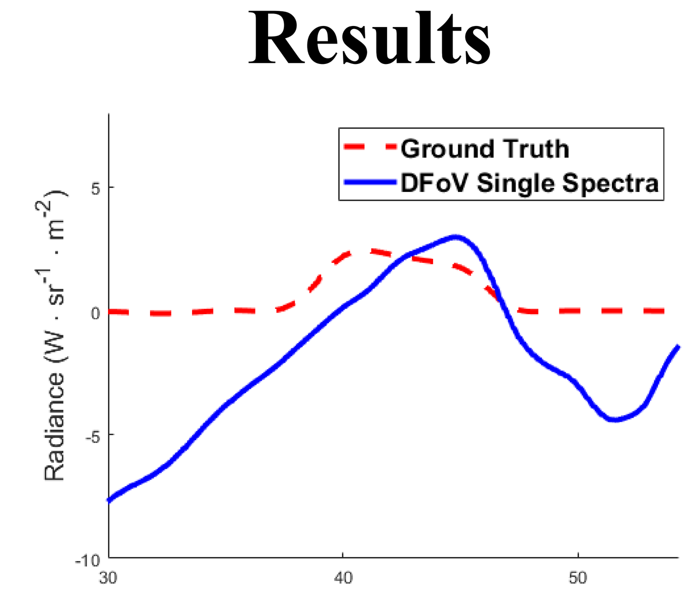


LCD scene split up into different RGB spectra

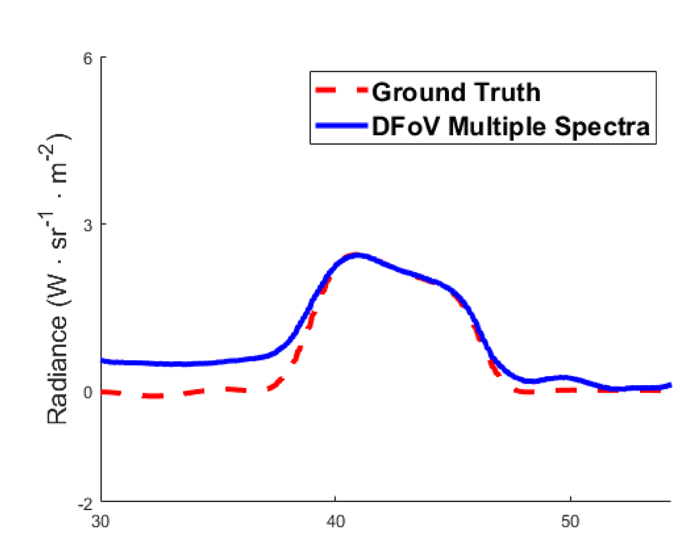
Results



Reconstructed object using only spatial data



Reconstructed object using a single-spectra light field



Reconstructed object using multiple-spectra light field

Future Work

- Develop methods to include priors (spectrum continuity, scene assumptions) into fusion
- Continue towards real-life applications where clutter and noise are overwhelming
- Expand data fusion framework to include more electromagnetic spectra

Di Lin, Connor Hashemi, and James R Leger. "Non-Line-of-Sight Imaging using Plenoptic Information." *Computational Optical Sensing and Imaging*. Optical Society of America, 2019.

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