# Thermal Non-Line-of-Sight Imaging

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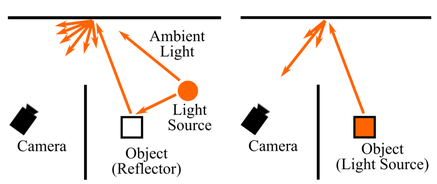
## How to see around corners?

We propose a novel non-line-of-sight (NLOS) imaging framework with long-wave infrared (IR). Surface reflectance has a much stronger specular reflection in the long-wave IR spectrum than in the visible light spectrum. We reformulate a light transport model that leverages these favorable physical properties of long-wave IR. Specifically, we demonstrate 2D shape recovery and 3D localization of a hidden object. Furthermore, we demonstrate near real-time and robust NLOS pose estimation of a human figure, the first such demonstration, to our knowledge.



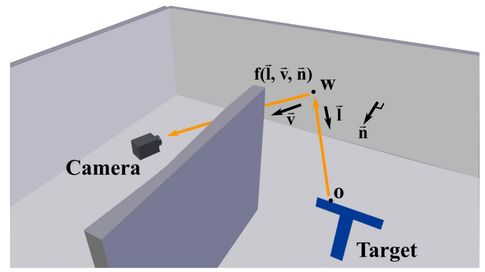

(a) Visible spectrum (0.4 - 0.7μm) (b) Long-wave IR spectrum (8 - 14μm)

(a) The visible light problem is a two-bounce problem, where the hidden object is a reflector. (b) The long-wave IR problem is a one-bounce problem since the hidden object is a light emitter.

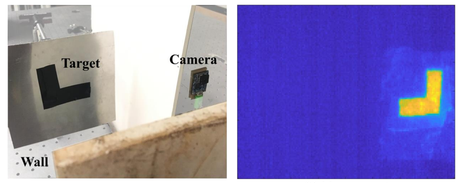
| | ToF | Coherence | RGB | Proposed |
|---|---|---|---|---|
| Illumination | Active | Active | Passive | Passive |
| Cost | High [a] | Low | Low | Low |
| Ambient Light | Robust | Not Robust | Not Robust | Robust |
| Depth Resolution | Fine | None[b] | Coarse[c] | Coarse |
| 2D Shape Resolution | Fine | Fine | Coarse | Fine |

Comparing the proposed methods with the related NLOS imaging methods.

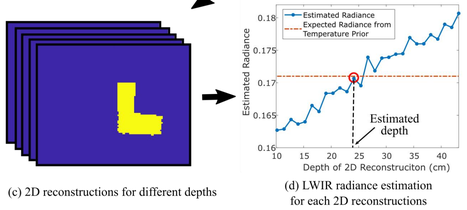
## Our Novel Approach: Integrate Thermal BRDF Model with Pose Estimation




The canonical scene setup consist of a camera looking at the wall at a corner.




(a) Corner setup (b) Measurement (Object 25.4cm away from wall)




(c) 2D reconstructions for different depths (d) LWIR radiance estimation for each 2D reconstructions

Reconstruction algorithm for 2D shape recovery and 3D localization.

$$f(\vec{\mathbf{l}}, \vec{\mathbf{v}}, \vec{\mathbf{n}}) = \frac{D(\vec{\mathbf{h}}, \vec{\mathbf{n}}) F(\vec{\mathbf{v}}, \vec{\mathbf{h}}) G(\vec{\mathbf{l}}, \vec{\mathbf{v}}, \vec{\mathbf{h}}, \vec{\mathbf{n}})}{4(\vec{\mathbf{l}} \cdot \vec{\mathbf{n}})(\vec{\mathbf{v}} \cdot \vec{\mathbf{n}})},$$

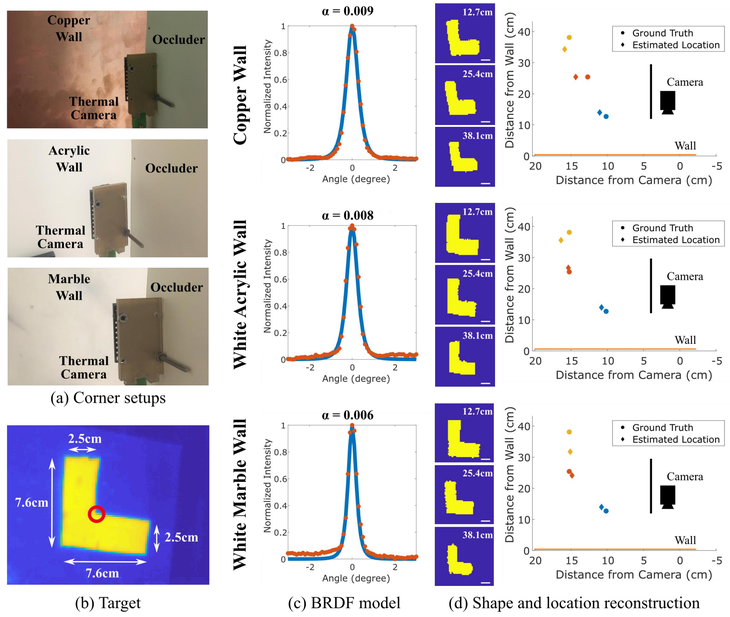
BRDF model

$$\hat{\mathbf{x}}_i \approx \mathbb{I}\left\{ \sum_{j=1}^{m} \mathbb{I}\{\mathbf{M}_{ji} \geq \gamma_1\} \mathbb{I}\{\mathbf{y}_j \geq \gamma_2\} \geq 1 \right\},$$

2D shape recovery

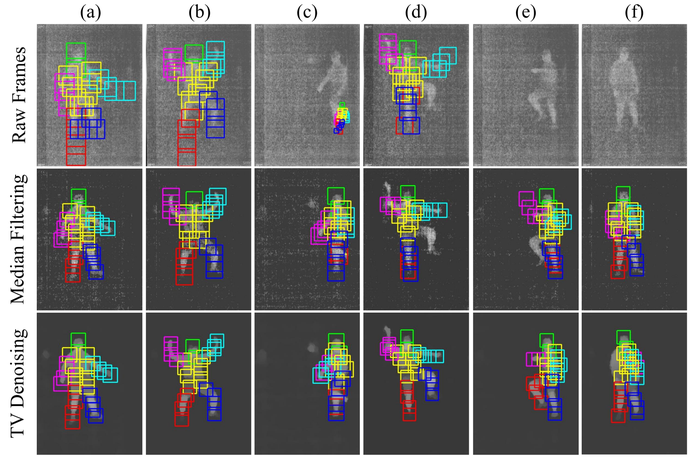
$$\hat{E}_{obj}^{(i)} = \arg\min_{E} \left\| \mathbf{y} - E\hat{\mathbf{A}}^{(i)}\hat{\mathbf{x}}^{(i)} \right\|^2,$$

3D localization

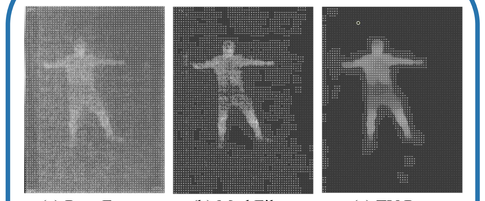



(a) Corner setups (b) Target (c) BRDF model (d) Shape and location reconstruction

NLOS scene reconstruction results. (a) Corner setups.(b) Thermal image of the target. (c) BRDF is fitted with GGX specular BRDF model. (d) Localization of the target.

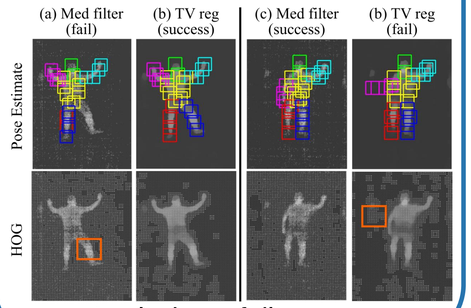



NLOS pose estimation results.



(a) Raw Frame (b) Med Filter (c) TV Reg

Comparing HOG features in raw frames and denoised frames.




Analysis on failure cases.

## Conclusion

We believe that long-wave IR could be the method of choice to see around corners for many applications. Our results are powered by the simplicity of a one-bounce problem and a strong specular surface reflectance. Future work can build upon such favorable physics to further realize the vision of a camera that can see around corners.

## References

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[4] Tomohiro Maeda, Yiqin Wang, Achuta Kadambi, Ramesh Raskar. "Non-line-of-Sight Imaging by Exploiting Unique Properties of Long-Wave IR" ICCP 2019.