# Looking Around Flatland: A Physically-Based Simulation System for Real-Time NLOS Imaging

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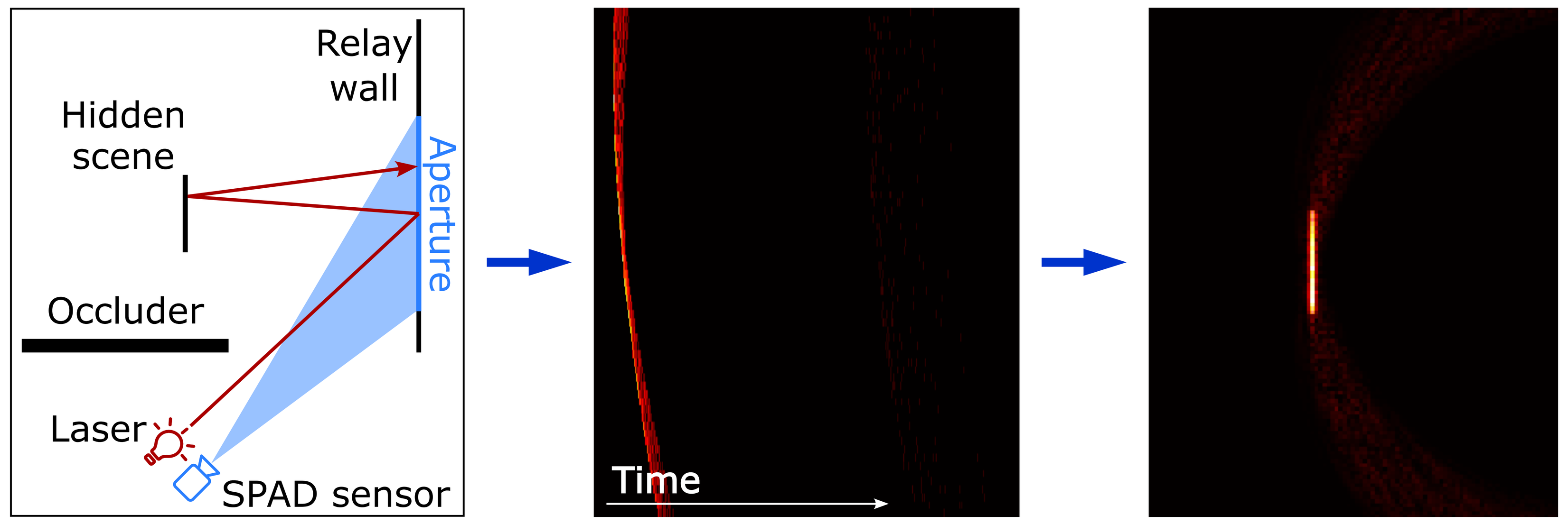
Time-gated non-line-of-sight (NLOS) imaging methods reconstruct scenes hidden around a corner. Time-resolved light transport simulation is a useful tool for NLOS method analysis and prototyping but has prohibitive computational and memory constraints. We present a simulation-based NLOS imaging pipeline that couples physically-based transient rendering in 2D scenes with NLOS imaging reconstruction methodologies, providing real-time results and comprehensive control of scene and imaging parameters, due to dimensionality reduction.

## NLOS Imaging Pipeline

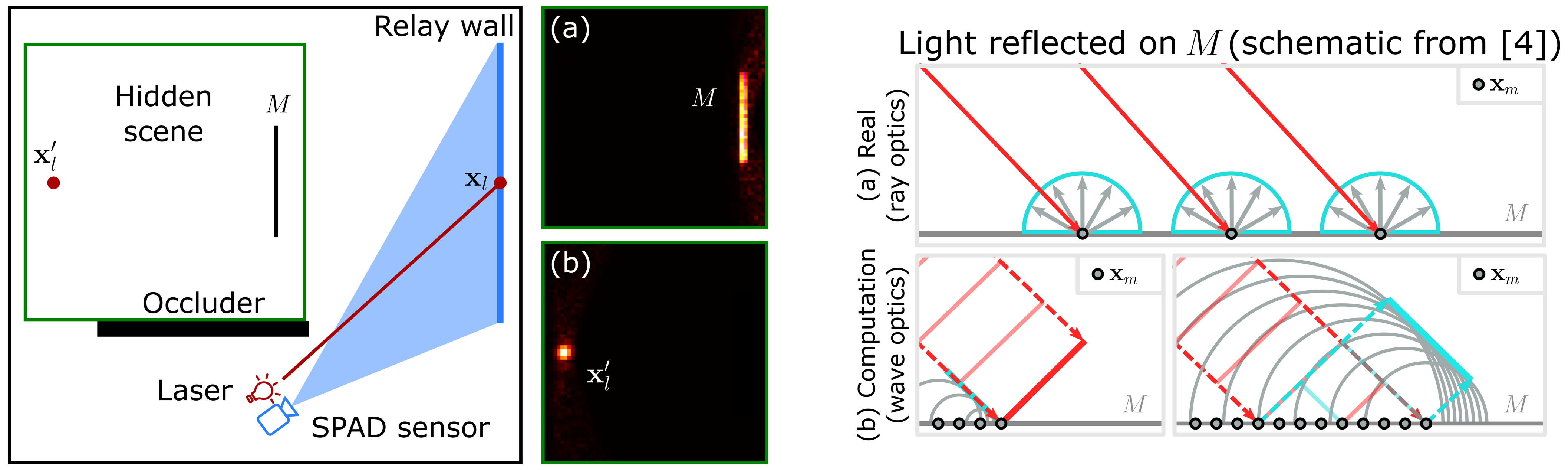
- The hidden scene is illuminated with an ultra-fast laser pulse sent to a relay wall.
- A SPAD-based sensor captures time-resolved indirect illumination at the visible relay surface.
- The hidden scene is reconstructed based on the time-of-flight of third-bounce light paths.
- Recent phasor-based methods [3] formulate NLOS imaging models based on virtual wave propagation.




Illumination and capture  Time-resolved image  Reconstruction

- Simulation allows additional control over scenes, but it has the following challenges:
  - Time-resolved light transport simulation is computationally expensive.
  - Generated files require large storage space.
  - Analysis of light transport and NLOS imaging results is counter-intuitive for high-dimensional spaces.

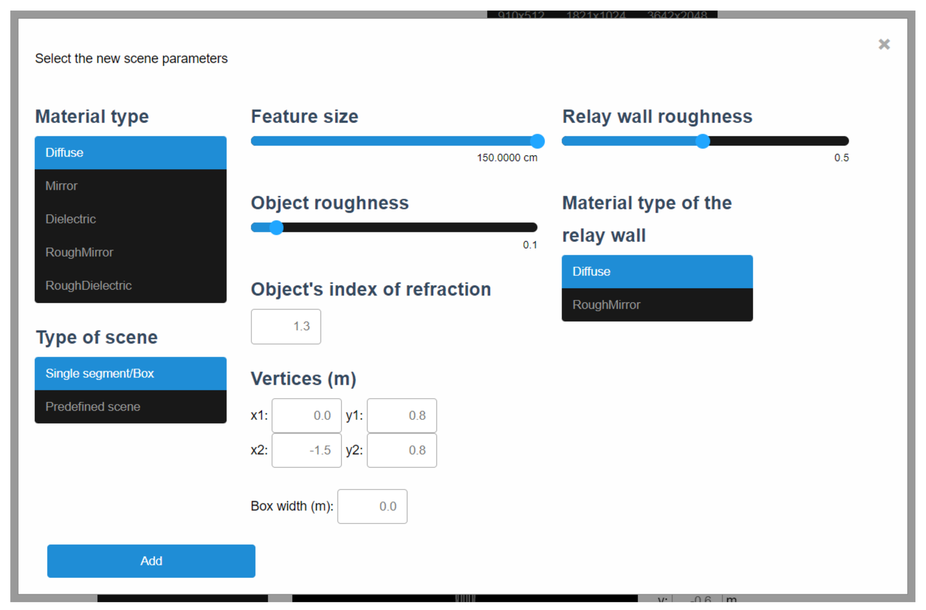
## Validation of Previous Methods in 2D

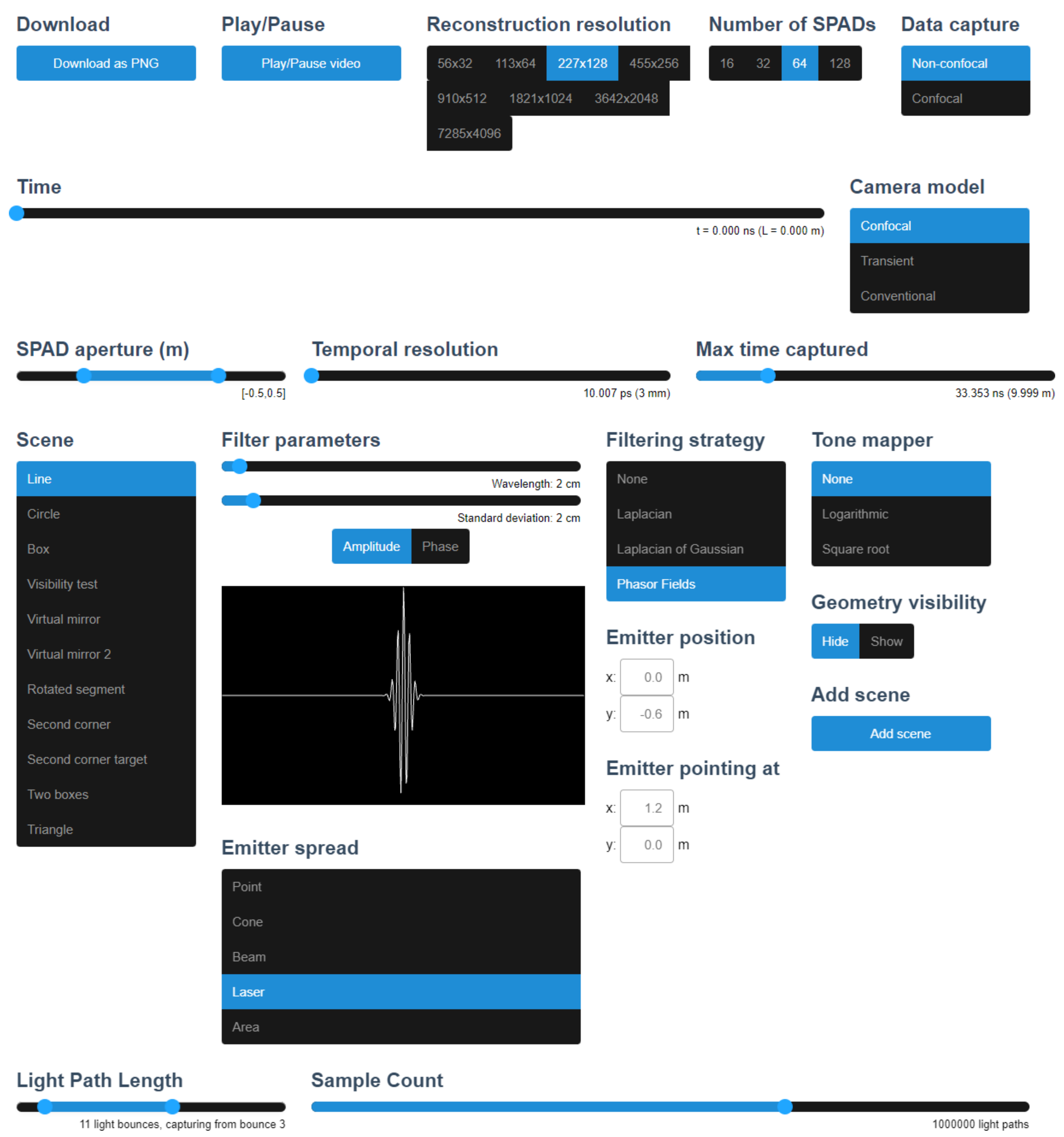



- We validate our system by replicating previous works in our two-dimensional simulation system.
- We implement classic third-bounce reconstruction methods in 2D, which are able to reconstruct planar object $M$ (left image, a).
- Planar surfaces that are diffuse in the real domain (right image, a) may exhibit specular behavior in the computational domain [4], as described by wave interference and Huygens's principle (right image, b).
- Our system is capable of reproducing this behavior, allowing to observe a mirror reflection of the light source under a different imaging modality (left image, b).

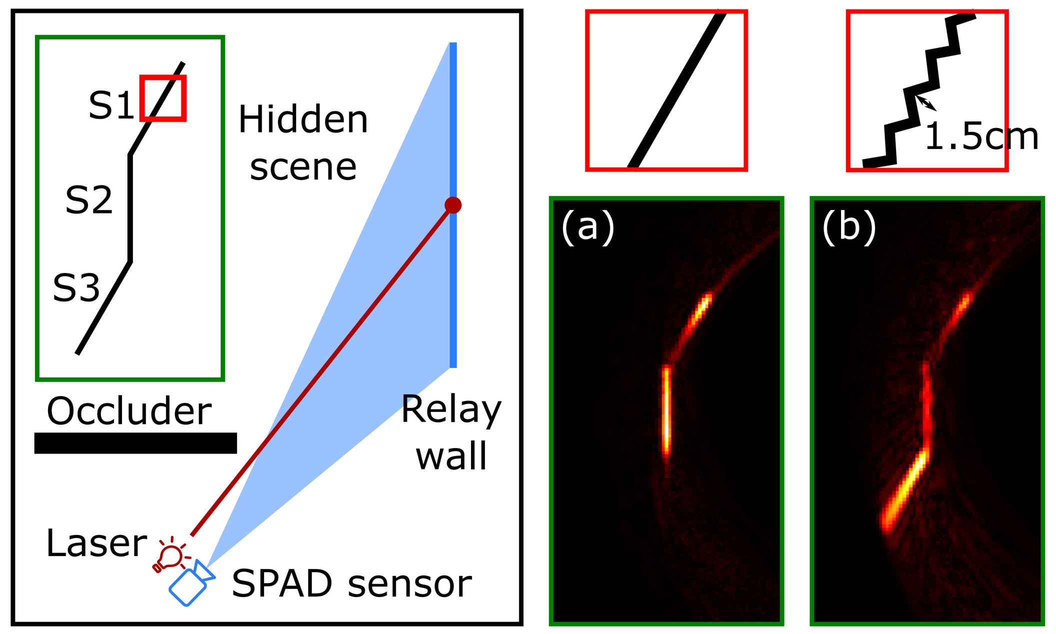
## Our 2D End-to-End Simulation System

- We reduce the dimensionality of the problem by removing one spatial dimension.
- Our system extends the WebGL-based 2D rendering engine Tantalum [1] to simulate the capture process, and uses the phasor-field formulation [3] to implement different virtual imaging models.
- The entire pipeline operates in real-time.
- It offers many configuration options, such as changing the capture configuration, or modifying the virtual imaging function and the properties of the hidden scene.

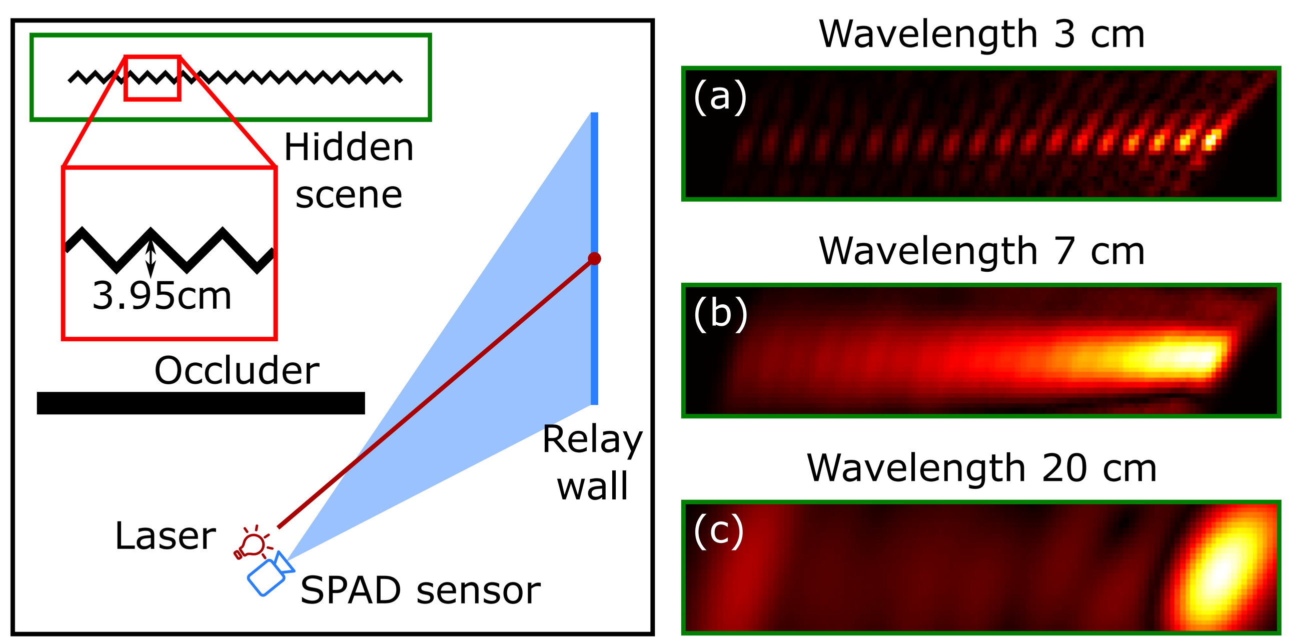



## Visibility Analysis




- The missing cone problem describes how some surfaces at certain positions and orientations cannot be reconstructed by third-bounce methods.
- We replicate Liu et al.'s analysis [2] in 2D, where planar segment S3, faced away from the relay wall, cannot be reconstructed (a).
- We use our 2D simulation system to further analyze visibility. By changing the local structure of the hidden object, we observe how S3 becomes visible in the reconstruction (b).




- Our system allows us to explore the effect of different virtual imaging wavelengths to reproduce local features on a globally planar object.
- Local features can be resolved individually when their size and the chosen wavelength are close (a).
- Using a larger wavelength, only the global shape of the object is reconstructed (b).
- If the wavelength is too large, the reconstruction is blurred and we cannot distinguish the shape of the object (c).

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**References**

[1] - Bitterli, B. 2015. The Secret Life of Photons. URL: https://benedikt-bitterli.me/tantalum/.
[2] - Liu, X. et al. 2019. Analysis of Feature Visibility in Non-Line-Of-Sight Measurements. CVPR.
[3] - Liu, X. et al. 2019. Non-line-of-sight imaging using phasor-field virtual wave optics. Nature 572.7771.
[4] - Royo, D. et al. 2023. Virtual Mirrors: Non-Line-of-Sight Imaging Beyond the Third Bounce. ACM Trans. Graph. 42.4.

**Acknowledgments**

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