3D Reconstruction in Low Light using Single-Photon Gaussian Splatting

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In robotics and autonomous navigation, training AI models is challenging due to rare, edge cases. 3D Digital Twins offer a simulation-based solution [1], utilizing Structure-from-Motion (SfM) [2] and 3D Gaussian Splatting (3DGS) [3] for high-fidelity scene reconstruction and rapid rendering. However, these methods are constrained by input quality; traditional CMOS sensors suffer from prohibitive read noise and motion blur in low-light conditions, leading to fragmented reconstructions. We demonstrate the first application of the Canon MS-500 SPAD sensor [4] for high-resolution 3DGS in sub-lux environments, overcoming these fundamental sensing.

Fig. 1: A re*al (left) evaluation frame from scenario 1 vs. matching reconstructed viewpoint (right).*

We recorded one-minute trajectories of a cluttered laboratory scene using the Canon MS-500 SPAD camera under two distinct lighting conditions. For each sequence, approximately 300 frames were processed using COLMAP [2]. Scene synthesis was performed via gsplat [5] for 30,000 iterations. To quantify reconstruction quality, every 8th frame was reserved as a hold-out set. We evaluated the model using Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Learned Perceptual Image Patch Similarity (LPIPS) [6]. Fig. 1 illustrates the high fidelity of the rendered view compared to the ground-truth evaluation frame, while Table 1 summarizes the quantitative performance. Interactive 3D visualizations of the reconstructions are available at the provided links.

Table 1: Reconstruction results

	Light Level	PSNR	SSIM	LPIPS	Results
Scenario 1	0.5 lux	18.84	0.21	0.88	Link
Scenario 2	1 lux	26.49	0.59	0.53	Link

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References

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