

Joint Event-Frame Phase Retrieval in Inline Holography

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Abstract: We report a joint event-frame phase retrieval method for dynamic-range-limited in-line holography, where asynchronous events provide complementary feature-domain constraints that improve complex-field reconstruction over single-modality inversion. © 2026 The Author(s)

1. Introduction

Digital holography recovers the complex optical field from recorded interference patterns and provides a compact framework for phase retrieval and wavefront sensing [1]. Yet reliable reconstruction becomes increasingly challenging under measurement-limited regimes, particularly when the hologram is acquired with limited photon budget or compressed dynamic range, where saturation, noise, and contrast loss weaken the structural variation available for inversion. Under such conditions, frame-only complex-field recovery becomes increasingly ill-conditioned. Recent feature-domain phase-retrieval methods mitigate this problem by replacing intensity-domain losses with feature-domain constraints, often formulated on logarithmic-intensity gradients, allowing partially vignetted or aperture-truncated measurements to remain usable [2]. Nevertheless, such features are still inferred indirectly from the same degraded frame observation. Their effectiveness therefore remains fundamentally constrained when the spatial-domain hologram itself is severely corrupted.

Event cameras offer an attractive complementary sensing modality because they respond to photometric changes with microsecond temporal resolution and a high dynamic range (HDR) of approximately 140 dB. Therefore, they are particularly suitable for dynamic optical-field sensing tasks [3, 4]. Our previous event-assisted holographic imaging studies further showed that, in inline holography, event measurements can serve as photometric gradient constraints through temporal diversity measurements for event-only optical-field recovery [5]. These results establish events as a direct HDR source of photometric gradient features and, in turn, motivate the joint event-frame optimization framework presented here.

2. Principle

Event cameras asynchronously record changes in logarithmic intensity at microsecond latency. Since each event encodes a local temporal increment in logarithmic intensity, the event stream provides a sparse but direct measurement of photometric variation in the spatial gradient. For sufficiently small transport, this variation follows

$$\Delta L(\mathbf{x}) = -\nabla L(\mathbf{x}) \cdot \mathbf{v}, \quad (1)$$

where $L = \log I$ denotes the logarithmic hologram intensity, ∇L its spatial gradient, and $\mathbf{v}$ the transport field during the measurement interval. This relation shows that event measurements provide direct HDR access to photometric gradient features that are complementary to conventional frame measurements.

In inline holography, the latent complex field $U_0 = ae^{j\phi}$, where a and ϕ denote the amplitude and phase, respectively, is linked to the recorded frame hologram through free-space propagation,

$$I(\mathbf{x}) = |U_0 * h_z|^2(\mathbf{x}), \quad U_z(\mathbf{x}) = \mathcal{F}^{-1}\{\mathcal{F}\{U_0(\mathbf{x})\}H_z(\mathbf{f})\}, \quad (2)$$

where h_z denotes the propagation kernel and $H_z(\mathbf{f}) = \exp\left(-i\frac{2\pi z}{\lambda}\sqrt{1 - \lambda^2 \mathbf{f}^2}\right)$ is the transfer function within the propagating band. We recover the latent complex field by jointly minimizing the frame-domain and event-feature-domain discrepancies,

$$\hat{U}_0 = \arg \min_{U_0, z, \mathbf{v}} \|I - y_F\|_2^2 + \alpha \|\nabla L \cdot \mathbf{v} + y_E\|_2^2 + \beta \mathcal{R}(U_0), \quad (3)$$

where I denotes the hologram intensity predicted from the latent complex field, y_F is the measured frame hologram, and y_E denotes the corresponding event-derived feature measurement. Here, $\nabla L \cdot \mathbf{v}$ represents the predicted

photometric gradient feature-domain response over the measurement interval, and $\mathcal{R}(U_0)$ is a regularizer, such as total variation (TV), that stabilizes latent complex-field recovery. This differentiable formulation jointly enforces frame-domain hologram consistency and event-feature-domain consistency, enabling improved amplitude and phase recovery under dynamic-range-limited sensing.

3. Result and Conclusion

Figure 1 summarizes the proposed joint event–frame optimization for dynamic-range-limited holographic complex-field recovery. As shown in Fig. 1a, the jointly optimized model achieves improved agreement with both the measured frame hologram and the event-derived feature response, compared with frame-only prediction. The resulting optical-field retrieval in Fig. 1b further demonstrates improved reconstruction of both amplitude and phase, with enhanced structural fidelity in the highlighted regions relative to back-propagation and frame-only optimization. These results support the feasibility of recovering the latent complex field by jointly enforcing frame-domain hologram consistency and event-feature-domain consistency within an optimization framework.

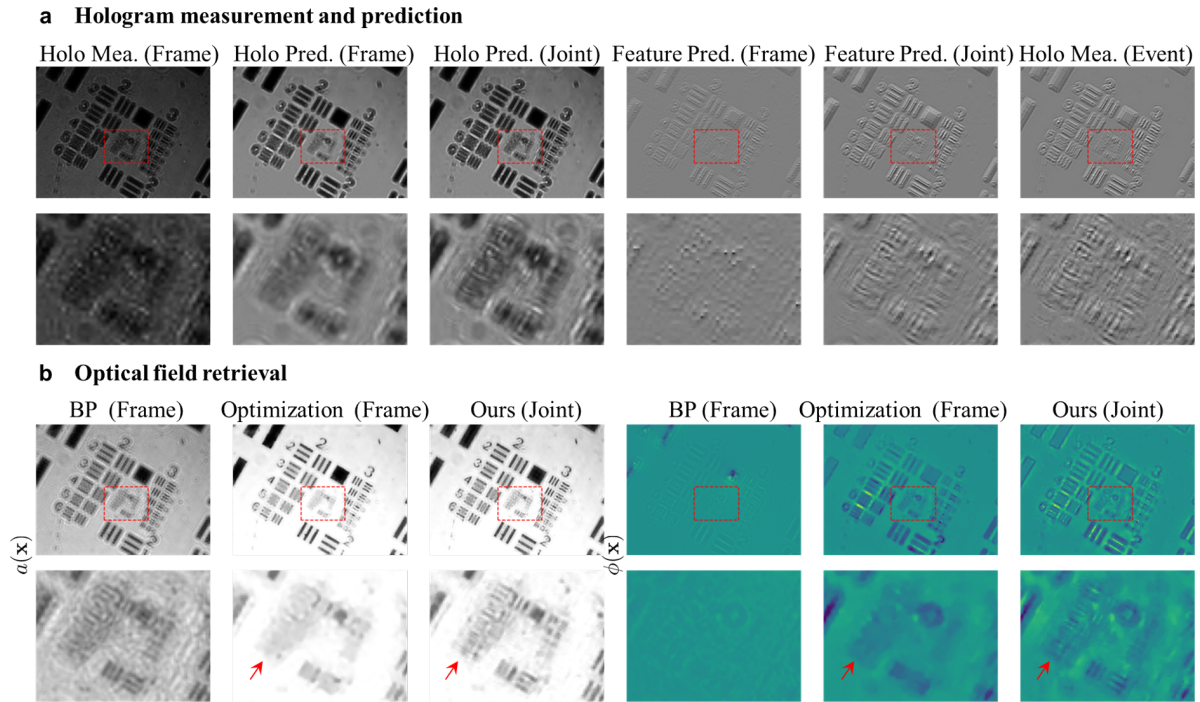


Fig. 1. **Joint event–frame optimization for holographic complex-field recovery.** **a**, Hologram and feature-domain measurements and predictions. Joint optimization improves agreement with both frame and event-feature measurements. **b**, Retrieved amplitude $a(\mathbf{x})$ and phase $\phi(\mathbf{x})$. Compared with back-propagation (BP) and frame-only optimization, the proposed method yields cleaner recovery.

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