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Lightweight multi-wavelength network model for efficient and high-fidelity full-color 3D holographic display

The popularity of deep learning has boosted computer-generated holography (CGH) as a vibrant research field, particularly physics-driven unsupervised learning.

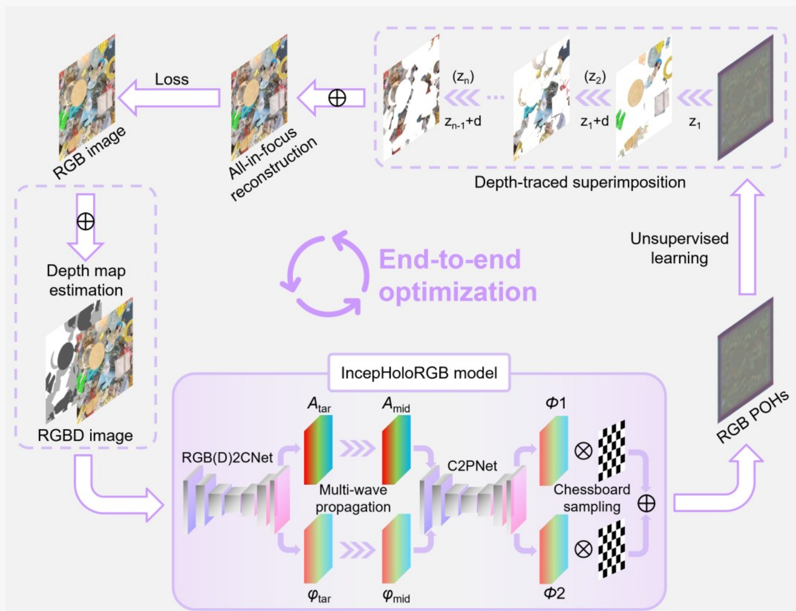

Fig 1: Full-color hologram generation workflow of IncepHoloRGB.

CHENGDU, SICHUAN, CHINA, November 3, 2025 /EINPresswire.com/ -- Computer-generated holography (CGH), as one of the most attractive next-generation three-dimensional (3D) display technology, possesses the capacity to provide authentic depth cues of 3D scenes via faithfully recording the optical field with computational simulations and loading the calculated holograms to reconstruct the target scenes. However, the process of hologram generation is predominately an ill-posed inverse problem, since only the intensity or amplitude information of the target scene is known while the original wavefront phase remains inaccessible in the initial calculation of holograms.

Conventional CGH methods are all facing a fundamental trade-off between reconstruction fidelity and computational efficiency which prevents from meeting the escalating demands for high-quality, full-color, naked-eye 3D display in modern information applications. Deep learning-based CGH models have emerged as a transformative solution to the longstanding quality-speed trade-off in hologram generation with the development of artificial intelligence (AI) algorithms and high-performance computing hardware like graphics processing units (GPUs). Common supervised approaches require massive dataset comprised of target scenes and corresponding pre-computed holograms for fitting the mapping relationship, which is a process fundamentally constrained by the inherent paradox that perfect hologram pre-calculation through conventional methods remains unattainable due to the ill-posed nature of inverse problems.

To address this limitation, physics-driven unsupervised models have leveraged the learning abilities of deep neural networks (DNNs) informed by wave optics principles instead of treating networks as black-box approximators, enabling high-quality hologram generation without label holograms. Nevertheless, present unsupervised models predominantly focus on one certain aspect in CGH. Some models generate single-wavelength holograms limited to monochromatic 2D display, or obtain RGB holograms through three separate single-wavelength network models that triple computational resource consumption, which is difficult to achieve efficient computing. On the other hand, although notable advances have been made in [3D holographic reconstruction], there is still a lack of comprehensive support in high resolution, full-color display and multi-depth-varying perception using a single high-performance model.

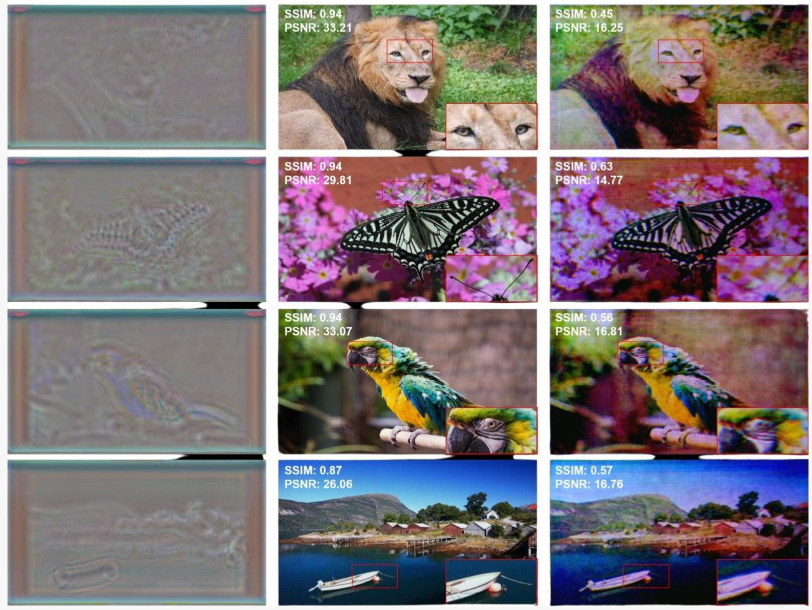

Fig 2: Holographic display of 2D scenes from IncepHoloRGB. (a) RGB POHs generated by IncepHoloRGB. (b) Numerically simulated reconstruction from (a) with details magnification in red boxes. (c)Optically experimental reconstruction from(a)with details magnification in RB

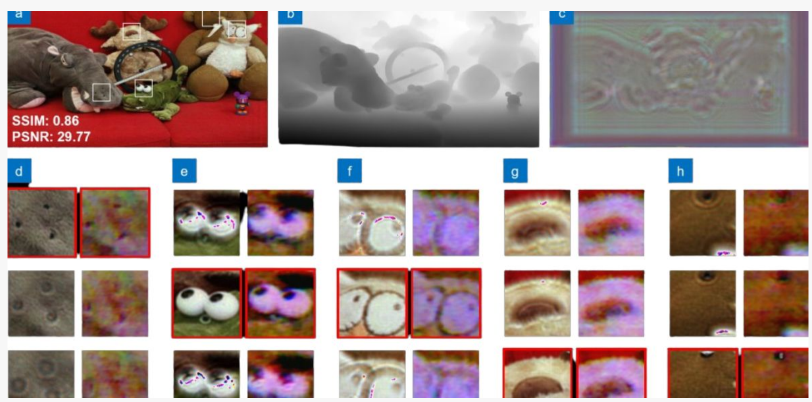

Fig 3: Holographic display of 3D scenes from IncepHoloRGB. (a) Numerically simulated reconstruction of all-in-focus image. (b) Depth map predicted by Boosting Monocular Depth model. (c) RGB POHs generated by IncepHoloRGB. (d) (e) (f) (g) (h) Numerically simulated....

About the Research group:

The research group of Prof. Wei Xiong and Hui Gao from Wuhan National Laboratory for Optoelectronics in Huazhong University of Science and Technology propose a [lightweight unsupervised CGH model named IncepHoloRGB], which generates RGB full high definition (FHD) resolution (1920×1080) holograms simultaneously through a unified framework fulfilled in both 2D and 3D display mode. To obtain vivid 3D visual cues, a depth-traced superimposition method is proposed to ensure the consistency of front-rear spatial relationships, in which the images of subsequent layers are directly calculated from the amplitude and phase of the previous layer's optical field. This process inherently involves the near-far nature of different depth layers while enabling the generation of holograms through pure unsupervised learning without any pre-computed label holograms.

To further enhance the representation learning capability of neural networks in full-color and high-resolution hologram generation, Inception sampling block is proposed, which consists of 4 paths with small convolution kernels (1×1, 2×2 or 3×3) to implement multi-scale feature extraction and processing prominently enhances the computing efficiency with high reconstruction fidelity. The core concept of Inception sampling blocks is the extensive use of 1×1 convolutions, which reduces computational costs and avoids the computational overhead caused by directly using large convolution kernels.

Combined with differentiable multi-wavelength propagation module that can simultaneously support diffraction field propagation for RGB wavelength channels with high computational accuracy and trained via hybrid loss function for color perception, the scalability of IncepHoloRGB is demonstrated with full-color scenario reconstruction in both simulations and experiments, which can achieve high-performance hologram generation for full-color holographic 2D and 3D display with better visual impression than previous CGH methods. This lightweight network model significantly optimizes computational efficiency through parallel computing while attaining 0.88 SSIM and 29.00 PSNR with 191 FPS in hologram reconstruction, promising potential unprecedented capabilities for real-time dynamic 3D display systems such as virtual and augmented reality (VR/AR).

About the Authors:

Professor Xiong Wei and Associate Professor Gao Hui lead the Micro & Nano Optoelectronics Laboratory at Huazhong University of Science and Technology (HUST), which is recognized as an Innovation Group in Hubei Province. The team primarily focuses on interdisciplinary research in laser micro-nano extreme manufacturing technologies and equipment. They have conducted pioneering work in advanced laser manufacturing technologies and metasurface-based micro-nano optical devices, successfully addressing multiple critical challenges in existing processing technologies including laser 3D/4D printing at micro-nano scales, optical field modulation with metasurfaces, holographic display, laser-based detection and anti-corrosion of high-performance materials, as well as high-efficiency laser micro-nano processing equipment. In recent years, they have published over 120 papers in internationally renowned journals such as Science Advances, Nature Communications, and Advanced Materials, and have applied for or been granted more than 50 domestic and international invention patents. The team has undertaken numerous national, provincial, and ministerial-level projects, as well as enterprise-sponsored projects, including those under the National Key Research and Development Program, National Major Scientific and Technological Infrastructure Projects, the National Natural Science Foundation of China General Program, and university-enterprise joint laboratories with funding reaching tens of millions of yuan. Over the past five years, the research team has received one Second Prize of the National Science and Technology Progress Award and one Second Prize of the National Teaching Achievement Award.

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