Generalized HoloTile and its Applications inIndustry and Academia

Madsen, Andreas Gejl; Glückstad, Jesper

Published in:
Proceedings Optica Digital Holography and Three-Dimensional Imaging Topical Meeting

DOI:
10.1364/DH.2024.M1B.4

Publication date:
2024

Document version:
Submitted manuscript

Citation for pulished version (APA):
Madsen, A. G., & Glückstad, J. (2024). Generalized HoloTile and its Applications inIndustry and Academia. In *Proceedings Optica Digital Holography and Three-Dimensional Imaging Topical Meeting* Optica Publishing Group. https://doi.org/10.1364/DH.2024.M1B.4

Digital Holography and Three-Dimensional Imaging © Optica 2024

Generalized HoloTile and its Applications in Industry and Academia

Andreas Erik Gejl Madsen,[1] Jesper Glückstad[2]

SDU Centre for Photonics Engineering, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark

[1] *gejl@mci.sdu.dk*

[2] *jegl@sdu.dk*

Abstract: HoloTile is an innovative holography technique for CGH, utilising sub-holograms and PSF shaping for high-resolution, speckle-reduced reconstructions. The paper introduces new HoloTile modalities and discusses applications like optical trapping, volumetric 3D printing, and quantum communication.

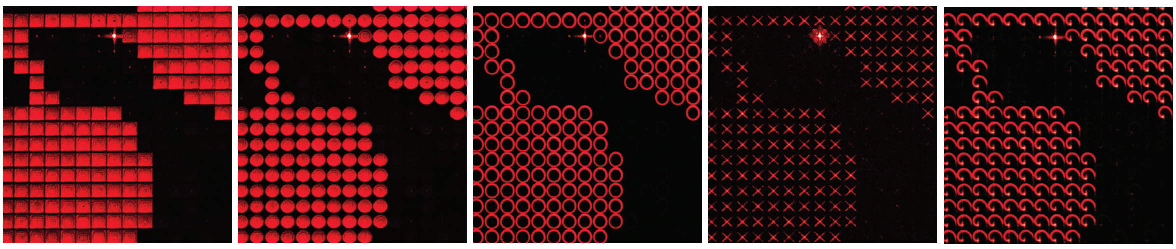
1. Main Text

Modern scientific advancements increasingly depend on the dynamic manipulation of coherent and semi-coherent light in multiple dimensions. This has broad applications in fields like neuroscience, microbiology, material processing, and advanced microscopy. Choosing the right light sculpting technique is vital for specific applications, such as micro-manipulation or microfabrication, where factors like photon efficiency and equipment size also play crucial roles. Phase-only modulation methods, like Computer Generated Holography (CGH), are often preferred for their efficiency in manipulating light without wasting photons.

A significant challenge in light sculpting is speckle noise, especially in applications requiring homogeneous light distribution. HoloTile, a patented CGH modality [1, 2, 3], addresses this issue in Fourier holography by reducing interference between adjacent frequency components. It offers advantages like rapid, speckle-free light sculpting, making it suitable for various applications including biophotonics, additive manufacturing, and display technology. HoloTile's speed and efficiency in hologram generation demonstrate its potential across numerous fields. Future research aims to integrate HoloTile into various optical systems for both industrial and academic uses, highlighting its versatility and efficiency in light manipulation.

1.1. *PSF Shaping Modalities*

The original HoloTile method can be adapted to produce a variety of pixel shapes, each with distinct applications. The process is flexible and can generate shapes like flat-top disks, rings, lines, multi-lines, and complex light distributions using specific phase functions [4, 5].



(a) Square pixels (b) Disk pixels (c) Ring pixels (d) Cross pixels (e) Helicoconical pixels

Fig. 1: The PSF shaping capabilities of HoloTile shown experimentally. For identical targets, the output pixels can be shaped near arbitrarily.

1.2. *Axial Propagation Charactaristics*

HoloTile enhances beam control in holography, allowing precise manipulation along both lateral and axial dimensions. Traditional methods limit control to specific reconstruction planes , where points interfere outside these planes. This often results in a noisy, indeterminate pattern beyond the reconstruction planes.

In contrast, HoloTile modifies the 3-dimensional Point Spread Function (PSF) through its beamshaping hologram. This innovation ensures consistent evolution of the reconstruction at each output pixel along the optical axis. Experimental results demonstrate this uniform axial propagation across all pixels, offering clear control over pixel alignment and interaction. Moreover, HoloTile facilitates advanced axial beam shaping. For example, by incorporating a quadratic phase term into the ring beam shaper, a Bessel-like beam is created, extending the axial range of the output beams significantly. This approach also simplifies the understanding and prediction of intra-pixel interference.

1.3. Applications

- Optogenetics: HoloTile addresses challenges in optogenetics by enabling precise light delivery for stimulating specific neurons. Its efficient light shaping capabilities and reduced speckle noise make it ideal for stimulating neurons using near-infrared light through two-photon processes. This approach is less scattered by brain tissue, providing deeper penetration and spatial selectivity. HoloTile's rapid and precise control over light patterns could revolutionize neurological research, potentially aiding in understanding and treating diseases like Alzheimer's and Parkinson's.
- Particle Manipulation: In optical trapping, traditional methods struggle with low refractive index or highly absorbing particles. HoloTile's ability to create high-efficiency, high-contrast dynamic ring patterns enables more effective manipulation of such particles. Its capability for real-time recalibration allows for precise, parallel optical manipulation, surpassing the limits of current technologies in light-robotics and other emerging fields [6].
- Laser Material Processing (LMP): In LMP, focused laser beams are used for tasks like engraving and welding. HoloTile enhances this process by allowing homogeneous, dynamic patterning, potentially increasing efficiency and fidelity in material surface processing. It could enable rapid and precise laser engraving on an industrial scale, offering a significant improvement over traditional methods.
- Volumetric 3D Printing: HoloTile [7] presents significant advantages in 3D printing, particularly in volumetric additive manufacturing (VAM). Its high light-transport efficiency and rapid hologram generation enable faster, higher resolution printing with potentially lower power requirements. HoloTile's versatility in creating controlled light patterns, such as Bessel-like beams, can facilitate printing complex structures without the need for support struts, revolutionizing the 3D printing industry.
- Information Transmission: The generation of optical vortices, such as helico-conical beams, is another remarkable application of HoloTile. These beams carry orbital angular momentum, increasing data transfer rates in both optical fibers and free-space communication. Moreover, HoloTile's ability to rapidly generate dynamic optical vortices in parallel opens up possibilities in quantum communication, utilizing them as qudits for higher information density, increased security, and efficient quantum computing.

References

[1] Jesper Glückstad. "HOLOGRAPHIC SYSTEM WITH IMPROVED PROJECTION QUALITY (EP 22169752.7)". Pat. EP 22169752.7. Apr. 2022.

[2] Andreas Gejl Madsen and Jesper Glückstad. "HoloTile: Rapid and Speckle-Suppressed Digital Holography by Matched Sub-Hologram Tiling and Point Spread Function Shaping". In: *Opt. Commun.* 525 (Dec. 2022), p. 128876. ISSN: 00304018. DOI: 10.1016/j.optcom.2022.128876. (Visited on 12/14/2022).

[3] Jesper Glückstad and Andreas Erik Gejl Madsen. "HoloTile Light Engine: New Digital Holographic Modalities and Applications". In: *Reports on Prog. Phys.* 87.3 (Mar. 2024), p. 034401. ISSN: 0034-4885, 1361-6633. DOI: 10.1088/1361-6633/ad2aca. (Visited on 02/28/2024).

[4] Carlo Amadeo Alonzo, Peter John Rodrigo, and Jesper Glückstad. "Helico-Conical Optical Beams: A Product of Helical and Conical Phase Fronts". In: *Opt. Express* 13.5 (Mar. 2005), p. 1749. ISSN: 1094-4087. DOI: 10.1364/OPEX.13.001749. (Visited on 02/23/2023).

[5] Vincent R. Daria, Darwin Z. Palima, and Jesper Glückstad. "Optical Twists in Phase and Amplitude". In: *Opt. Express* 19.2 (Jan. 2011), p. 476. ISSN: 1094-4087. DOI: 10.1364/OE.19.000476. (Visited on 06/30/2023).

[6] Jesper Glückstad and Darwin Palima, eds. *Light Robotics: Structure-Mediated Nanobiophotonics*. Nanophotonics Series. Amsterdam Oxford Cambridge, MA: Elsevier, 2017. ISBN: 978-0-7020-7096-9.

[7] Jesper Glückstad. "HOLOGRAPHIC VOLUMETRIC ADDITIVE MANUFACTURING, EP. 23205831.3". Pat. EP 23205831.3. 2023.