Weighted Dynamic Computer Generated Holography for 3D Image Display With a Commercial Video Projector

Jiayi Xu[1], Vincent R. Curtis[2], Nicholas W. Caira[2], and Nicolas C. Pégard[2,3,*]

[1]Department of Computer Science, [2]Department of Applied Physical Sciences, [3]Department of Biomedical Engineering,
[1,2,3]University of North Carolina at Chapel Hill, NC, USA. *pegard@unc.edu

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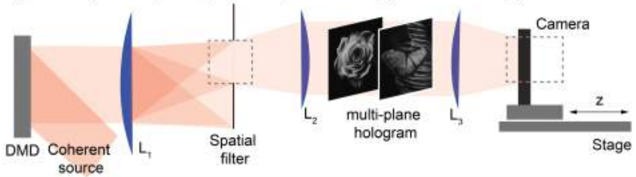
Abstract

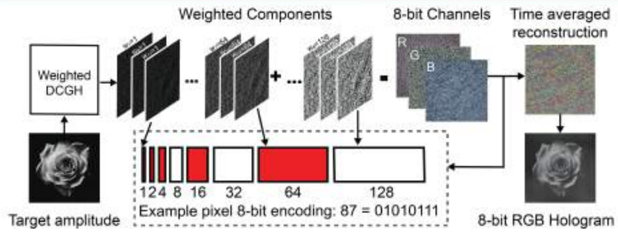
Computer generated holography (CGH) algorithms synthesize custom illumination patterns by modulating the phase or the amplitude of a coherent laser light source. With traditional CGH techniques, holograms are entirely determined by the 2D modulation applied to the light source. 3D images are always rendered approximately, and dominated by speckle noise. To render 3D images with improved fidelity, we have developed Dynamic Computer-Generated Holography (DCGH), a new holographic technique that rapidly superimposes a sequence of coherent waves to render the desired 3D scene with high fidelity and low speckle when their contributions are averaged out in time by the human eye. Here, we propose a practical implementation that enables easy, inexpensive DCGH hologram synthesis with a modified commercial video projector system. Our algorithm directly streams sequences of binary wave modulation patterns via the display port by encoding them as individual RGB images.

Experimental Setup

Patterns computed with our weighted DCGH algorithm are streamed to the 60Hz display port of a DMD (DLP6500), similar to commercial projectors. The modification we propose replaces the RGB sequential illumination with a coherent laser illumination on the DMD active area. A spatial filter eliminates undiffracted light, unwanted diffracted orders and symmetrical copies. To evaluate 3D display capabilities, the active window is imaged onto a CMOS camera using a 4-f lens relay (L2=Ll3=80mm). A 35 fps camera mounted on a translation stage averages the 24 coherent holograms contained in each RGB frame to capture the rendered 3D image at any focal plane, and as perceived by the human eye.

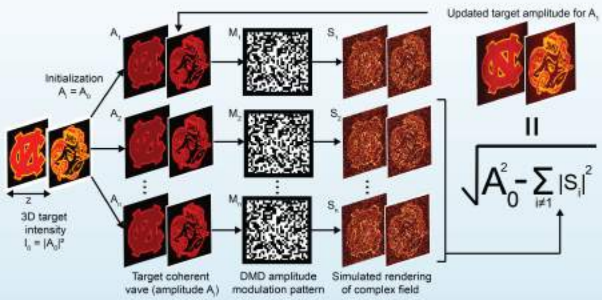


Encode DCGH holograms into RGB frames



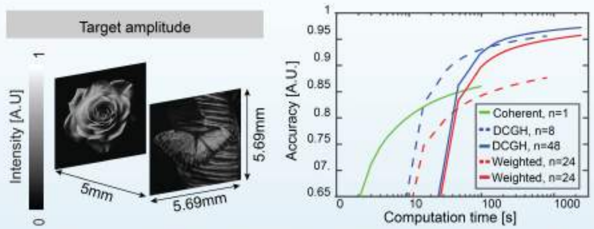
Video projectors display 8 bit RGB frames sequentially with one binary frame per bit and per color. To display DCGH holograms without modifying the electronic control of commercial video projectors, we decomposed our target intensity into groups of 8, 16, or 24 coherent waves, each contributing to a fractional amount of the total intensity with bit-weights $w = 2^0, 2^1, ..., 2^7$ for each channel.

Modified Gerchberg-Saxton (GS) algorithm for DCGH

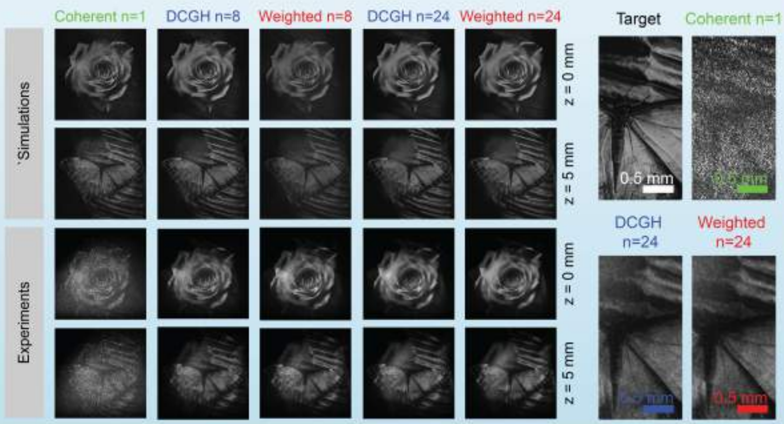


To render a 3D intensity distribution (defined as a stack of 2D image planes) with DCGH, we initialize our algorithm with n identical waves computed with one iteration of the GS algorithm. Coherent frames are then optimized sequentially. We begin by re-calculating the target intensity distribution for the first coherent frame. We subtract all the simulated renderings, including all the other (n-1) frames, from the original target intensity, then recompute the coherent hologram and its simulation. This process is repeated for all the frames in the sequence and again iteratively until the accuracy of the time-averaged rendered intensity reaches a maximum.

Simulation and Experiment Results



Our target image is made of two stacked unrelated natural images at depth 0 and 5 mm. We qualitatively observe that our weighted algorithm (in red) can yield high-fidelity, speckle-free holograms. We compared our technique to unweighted DCGH (in blue), and found that both approaches enable similar speckle reduction and image quality with significant benefits when compared to coherent CGH methods (in green). We then compared the accuracy of the rendered images across CGH methods. With n=8 frames, weighted DCGH and coherent CGH have similar accuracy, with only an 8% loss of image quality compared to unweighted DCGH. As we increase the number of frames, the disparity in accuracy decreases.



Conclusion

We have developed DCGH, a new method for generating high fidelity 3D holography. Our technique can be implemented by replacing the RGB light source of a commercial video projector with a laser and a software update. The result is an inexpensive solution for speckle-free, high resolution 3D light sculpting.

Reference

1. V.R. Curtis, N. W. Caira, J. Xu, A. G. Sata, and N. C. Pegard, DCGH: Dynamic computer generated holography for speckle-free, high fidelity 3D displays," IEEE VR (2021)

2. M. L. Huebschman, B. Munjuluri, and H. R. Garner, "Dynamic holographic 3D image projection, " Opt. express11, 437-445 (2003)