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HoloTile for Volumetric Additive Manufacturing

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Abstract: HoloTile [1, 2, 3, 4] is a novel digital holographic light sculpting modality with properties well suited to volumetric additive manufacturing (VAM). This paper discusses the consequences of moving from an imaging-based to a holographic-based VAM configuration, and how HoloTile may be used to improve volumetric printing further. © 2024 The Author(s)

1. Main Text

Utilizing a Fourier holographic setup, in which a hologram displayed on a Spatial Light Modulator (SLM) or Digital Micromirror Device (DMD) is spatially Fourier transformed into the printing volume, allows for interesting conclusions to be drawn in relation to Volumetric Additive Manufacturing (VAM)[5]. First of all, it allows us to depart from the local (4F) spatial transformation that occurs in imaging-based VAM configurations to a global (2F) transformation between the SLM and the printing volume. Specifically, in imaging-based VAM setups, which typically use amplitude modulating DMDs, each projected pixel in the printing volume corresponds directly to a physical pixel on the DMD. This effectively makes the light-efficiency i.e., the amount of light actually entering the printing volume, specific to any given printing pattern. The filtered Radon transform, which has become the de facto standard in tomographic VAM[6], produces sparse amplitude patterns, only activating a fraction of pixels in any given printing projection. Since the remainder of the light is simply discarded away from the printing volume, light efficiency can easily be less than 1%. Since a Fourier holographic setup can easily employ highly efficient phase-only SLMs utilizing the global transformation between SLM pixels and printing volume, light efficiency can approach 90 − 95%, regardless of the sparsity of the print patterns. This not only allows printing at much lower power and thus a much more flexible mechanical design, it also allows the use of single-mode light sources with much lower étendue, possibly increasing the print resolution through the printing volume. The 2F configuration, in combination with HoloTile, allows us to tailor the PSF of the system to our advantage. In practice, the reconstructed pattern from a HoloTile generated hologram can be expressed as a convolution between the patterned reconstruction of the subholograms $oh$, and the reconstruction of the SLM covering Point Spread Function (PSF) shaping hologram $o_{PSF}$:

$$o_{recon} = o_{PSF}(f_x, f_y, \Delta z, t) \otimes oh(f_x, f_y, t)$$  (1)

Fig. 1: Abstracted illustrations of setups for both (left) imaging-based tomographic VAM and (right) holographic VAM. Graphics: credit to Sammy Florczak, UM CU
Fig. 2: (left) Lateral cross section of axial propagation of Bessel-like beam shaped using HoloTile. (Right) experimentally captured axial sweep ($\Delta z = 2$ cm) of SDU logo with Bessel-like beams as output “pixels”.

This means that every activated output “pixel” defined in the subhologram reconstruction $o_H$ is shaped according to $op_{PSF}$. Thus, with a single analytically derived PSF shaping hologram, we can define and multiplex both the shape and the location of the pixel within its “unit cell” spatially, temporally, and even axially. With the PSF control of HoloTile, we observe well-behaved and predictable propagation outside of the focal plane of the Fourier transforming lens, and propagation specifically useful for VAM such as axially extended Bessel-like beams, as is shown in Figure 2. This beam shaping also extends to scattering and aberration correction. By monitoring the state of the print, it may be possible to compensate for both scattering and system aberrations in real-time by taking advantage of the unique PSF control of HoloTile. The wavefront control implicit in utilizing a holographic configuration also allows for pre-aberration of the printing beam in order to negate the effects of, for instance, an index mismatch in the printer.

Lastly, a Fourier holographic printing setup could, in principle, function using only a single lens which, incidentally, is optional, as its phase profile can easily be encoded on the SLM itself for a completely lensless setup. The reduction in both optical power and the number of required optical elements seriously impacts both cost and mechanical complexity of a possible commercial ultra-fast volumetric 3D printer.

References