Supplementary Material – PhlatCam: Designed phase-mask based thin lensless camera

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1 Video reconstruction

Supplementary attachement called 'Video_tikhonov.mp4' shows video reconstruction using PhlatCam. A frame of the video reconstruction is shown in main text Fig. 12. The reconstruction shown is Fig. 12 is with TV-regularization, while the reconstruction in the video file is performed using fast Tikhonov-regularized reconstruction.

2 3D Image roundtable

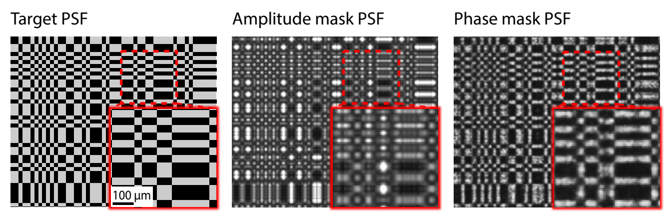
Supplementary attachement called '3Drecon.mp4' shows roundtable video of the 3D reconstruction. This reconstruction relates to main text Section 5.4.3.

3 Diffraction and Amplitude Masks

Besides the low light throughput limitation of amplitude masks (Main text Section 2.2.1), diffraction limits the space of realizable point-spread-functions (PSFs) by the amplitude masks. This directly affects the smallest feature size achievable in a PSF. Smaller features are desired in the PSF to achieve higher resolution [1], [2]. Additionally, if the PSF is designed to have some desirable properties like being separable [1], generating moire fringes [2], and having flat Fourier spectrum, diffraction effects will suppress these properties.

Amplitude masks are designed by mimicking the binary PSFs they need to produce — transparent (glass) where PSF is high and placing a blocking element (e.g. chrome on glass) where PSF is low. As a rule of thumb, the Fresnel number N_F associated with the amplitude mask can help in determining whether the PSF will be close to the pattern of the mask or different [3]. If the Fresnel number is much greater than 1, then geometrical properties are valid and the shadow PSF mimics the mask pattern. When the Fresnel number falls below 1, the cast PSF will deviate from the mask pattern.

For a fixed mask to sensor distance, the Fresnel number reduces as the feature size reduces and achieving PSFs with smaller features become unrealizable with amplitude masks. In contrast, phase masks are designed by incorporating diffraction or the wave optics model and doesn't suffer from such limitation. In Supp. Fig. 1, we compare the PSFs produced by amplitude mask and phase mask, each designed to produce the same target PSF. The sensor to mask distance is approximately 2 mm, and the smallest feature size is 24 μm. Diffraction effects are clearly visible in the amplitude mask PSF, while the phase mask PSF is closer to the target PSF.



Supp. Fig. 1. **Diffraction effects.** Target and achieved PSFs using binary amplitude mask and phase mask. The sensor to mask distance is approximately 2 mm, and the smallest feature size is 24 μm. Diffraction effects are clearly visible in the amplitude mask PSF, while the phase mask PSF is closer to the target PSF.

4 Numerical Fresnel Propagation

Numerically stable Angular spectrum method [3] was used to simulate Fresnel Propagation.

5 Spatial sparsity reason for PSF

In the design of Contour PSF, we mentioned four desired characteristics. The reason for spatial sparsity characteristic is explained below.

Since the PSFs are positive, the DC component (i.e., zero frequency) is going to have the highest contribution. However, most of the information is present in the higher frequencies. Hence, to increase the relative strength at higher frequencies, the DC component of the PSF needs to be reduced. A way to achieve low DC is by having sparsity in PSF or, in other words, a lot of zero-values.

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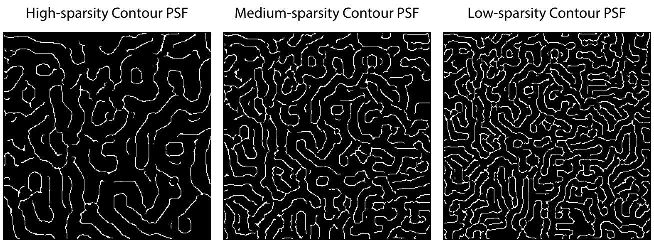
6 Varying Sparsity Contour PSFs

Contour PSFs of varying sparsity can be generated using Perlin noise [4] by varying the sampling parameter. Supp. Fig. 2 shows a few such variations.



Supp. Fig. 2. **Varying sparsity.** Contour PSFs generated with varying sparsity levels.

7 Diffusers

DiffuserCam [5] proposed an inexpensive lensless solution by using off-the-shelf diffusers as optical mask. Our method differs from [5] in the following two important ways. Our design framework allows (a) the flexibility of designing cameras of desired thicknesses, which is otherwise harder with the inherently statistical diffuser, and (b) to produce efficient PSFs designed for the intended purpose. To elaborate on (a), [5] used a 0.5deg diffuser, which experimentally produced the highest contrast PSF at around 9 mm. That is, choosing the diffuser determined the camera thickness while it is harder to choose a diffuser for a different desired camera thickness. On the other hand, we designed our phase mask for the desired camera thickness of less than 2 mm. When we tried to reproduce [5] using our 0.5deg diffuser (from the same vendor), we find that the highest contrast PSF appears at around 14 mm, showing the high variability in diffuser fabrication.

References

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