Phase contrast imaging with thin film notch filters

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Abstract: Notch filters are band-stop filters used to eliminate unwanted temporal frequencies. Here we demonstrate their capacity for phase contrast imaging of transparent objects enabled by its selective transmission. Applications in unstained biological imaging are anticipated.

Although exhibiting poor contrast under bright field illumination, shape and refractive index variations of transparent objects induce phase shifts in transmitted light, described by a transmission function $O(x,y) \approx O_0 e^{i\varphi(x,y)}$. Object-plane image processing with linear optical transfer functions can convert this phase information into measurable intensity variations, given

$$\nabla \mathrm{O}(\mathrm{x},\mathrm{y}) \supset \mathrm{i}\mathrm{O}_0\big(\nabla\varphi(x,y)\big)e^{i\varphi(x,y)}\,. \tag{1}$$

Notwithstanding recent meta-optical advances [1,2], it is timely to consider alternative devices with similar capabilities. Notch filters are band-stop filters used to remove unwanted temporal frequencies in signals [3]. However, dispersive band-rejection produces a high-pass transfer function with linear regions about $0.2k_0$, where k_0 is the wavenumber. Rotating the filter by 14° abouts its structural plane results in spatial differentiation along a direction normal to the rotation axis, thus resulting in phase contrast imaging.

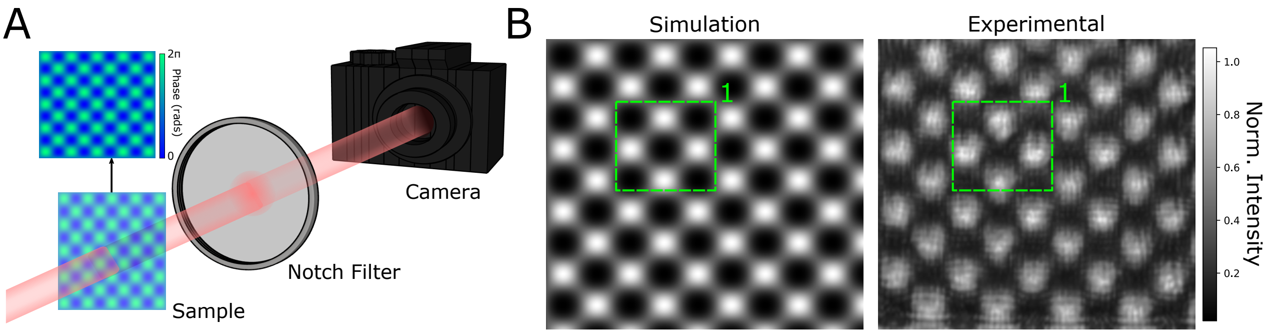

Fig. 1: A notch filter (Thorlabs NF633-25) was used to process a checkerboard pattern depicted in (A). Simulated and experimental phase images are given in (B).

As shown in Fig. 1, simulations and experiments were performed on a sinusoidal phase grating produced by a spatial light modulator. The filter enables visualization of otherwise invisible phase modulations. Potential applications are hence offered in biological cell imaging and dynamical monitoring.

[1] Y. Zhou, H. Zheng, I. I. Kravchenko and J. Valentine, *Nat. Photonics* **14**, 316-323 (2020).

[2] L. Wesemann, J. Rickett, J. Song, J. Lou, E. Hinde, T. J. Davis and A. Roberts, *Light: Sci. & Appl.* **10**, 98 (2021).

[3] C. A. F. Marques, V. de Oliveira, H. J. Kalinowski and R. N. Nogueira, *Opt. Lett.* **37**, 1697-1699 (2012).