Phase Retrieval Based Deconvolution Algorithm in Optical Systems

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Abstract

- In an optical imaging system, because the existence of the point spread function (PSF), the image cannot exactly represent the object.
- Deconvolution is an effective method to recover the object from the blurred image.
- But the detector only measures the intensity of light, not the phase. So the information used in image deconvolution is incomplete.
- Phase retrieval provides an effective method to recover the phase information from intensity measurements.
- With the complete field information, we can reconstruct the object more accurately.

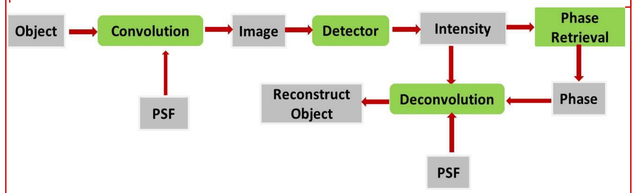


Fig. 1: Schematic illustration of the system model

Algorithm

The image formation model in an optical system can be expressed using the following linear formulation:

$$i(x,y,z) = o(x,y,z) * e_f(x,y,z),$$

$i(x,y,z)$ is the complex image at the detector, $o(x,y,z)$ is the object, $e_f(x,y,z)$ is the point spread function (PSF) of the imaging system.

$$e_f(\mathrm{x},\mathrm{y},\mathrm{z}) = 2\pi E_o \sum_{l=o}^{\infty} i^l j_l(kr) P_l cos(\theta) c_l,$$

In the Fourier domain, this model is expressed as

$$I(u,v,w) = O(u,v,w) \odot E_f(u,v,w),$$

The detector in an optical system only measures intensity, the measurements is

$$d(x,y,z) = |i(x,y,z)|^2 = |F^{-1}(I(u,v,w))|^2,$$

The model of phase retrieval in our system is

$$d_t(x,y,z) = |\langle \mathrm{a}_t, I(u,v,w)\rangle|^2, t = 1,2,...,m,$$

We use the Wirtinger Flow to recover the phase

Initialization $$I(u,v,w)_0 = \frac{1}{m}\sum_{t=1}^{m} d_t(x,y,z) a_t a_t^*,$$

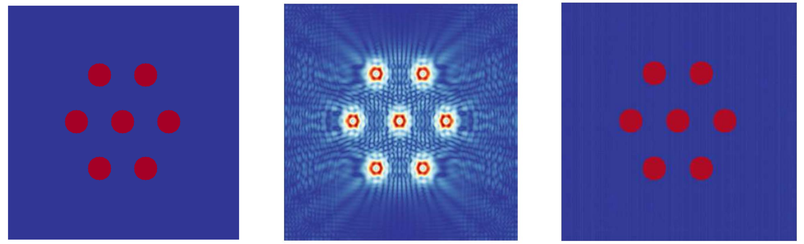
Minimize the lost function $f\left(I(u,v,w)\right) := \frac{1}{2m}\sum_{t=1}^{m}\left[d_t(x,y,z) - |a_t{}^* I(u,v,w)|^2\right]^2,$

The object can be recovered with deconvolution

$$O(u,v,w) = I(u,v,w) \oslash E_f(u,v,w),$$

$$o(x,y,z) = F^{-1}(O(u,v,w)),$$

Simulation Results



(a) true object *(b) measured optical image* *(c) reconstructed object*

Fig. 2: Performance of the proposed algorithm

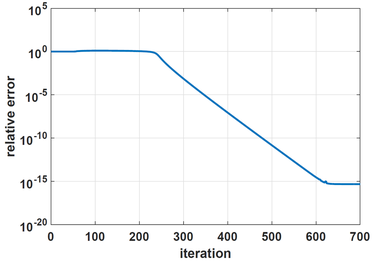


Fig. 3: error of the phase retrieval algorithm

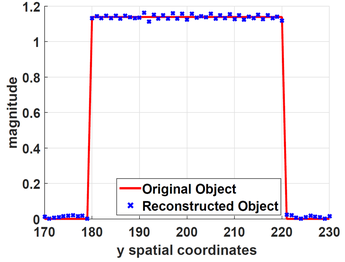


Fig. 4: amplitude comparison of the original and reconstructed object

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