Fourier ptychographic reconstruction using Poisson maximum likelihood and truncated Wirtinger gradient

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Fourier ptychographic microscopy (FPM) is a novel computational coherent imaging technique for high space-bandwidth product imaging. Mathematically, Fourier ptychographic (FP) reconstruction can be implemented as a phase retrieval optimization process, in which we only obtain low resolution intensity images corresponding to the sub-bands of the sample's high resolution (HR) spatial spectrum, and intend to retrieve the complex HR spectrum. In real setups, the measurements always suffer from various degenerations such as Gaussian noise, Poisson noise, speckle noise and pupil location error, which would largely degrade the reconstruction. To efficiently address these degenerations, we propose a novel FP reconstruction method under a gradient descent optimization framework in this paper, termed as truncated Poisson Wirtinger Fourier ptychographic reconstruction (TPWFP). The technique utilizes Poisson maximum likelihood for better signal modeling, and truncated Wirtinger gradient for error removal. Results on both simulated data and real data captured using our laser FPM setup show that the proposed method outperforms other state-of-the-art algorithms. Specifically, TPWFP owns following advantages over conventional techniques:

- The utilized Poisson maximum-likelihood objective function is more appropriate to describe the Poisson characteristic of the photon detection by an optical sensor in real imaging systems, and thus can obtain better results in real applications.
- Truncated gradient is used to prevent outliers from degrading the reconstruction, which provides better descent directions and enhanced robustness to various sources of error such as Gaussian noise and pupil location error.
- There is no matrix lifting and global searching for optimization, resulting in faster convergence and less computational requirement.

Also, we have released our source code for non-commercial use.

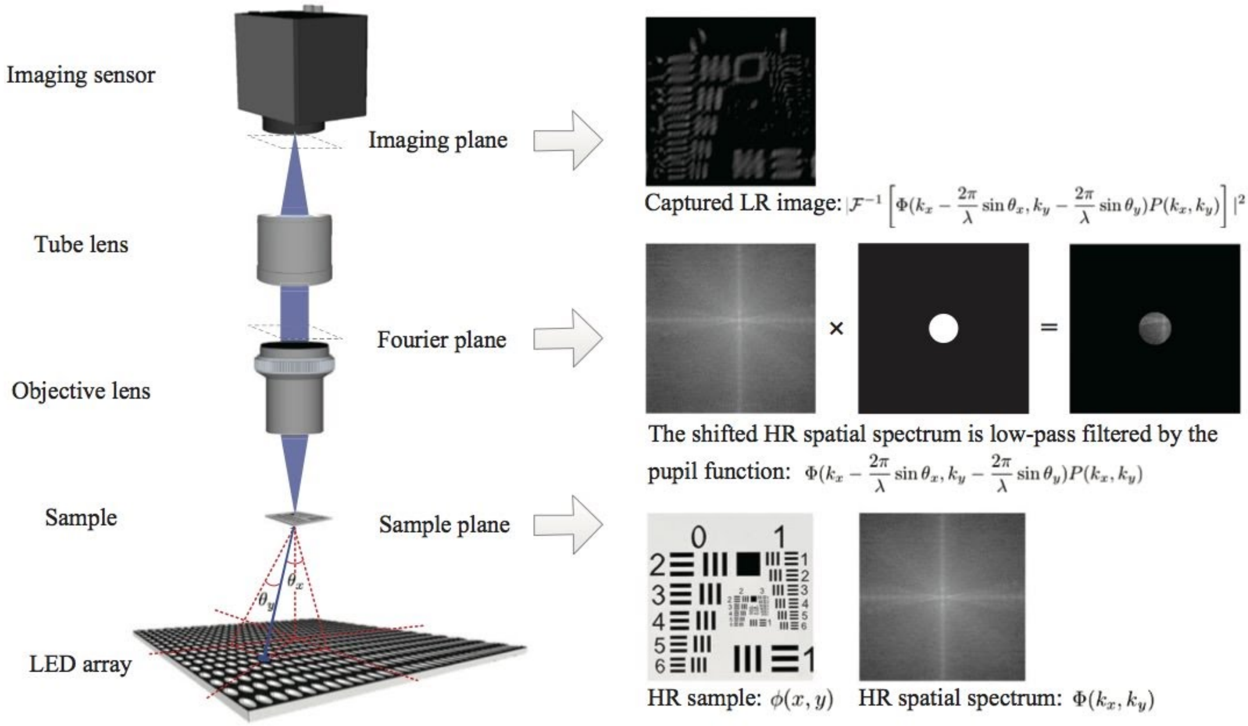
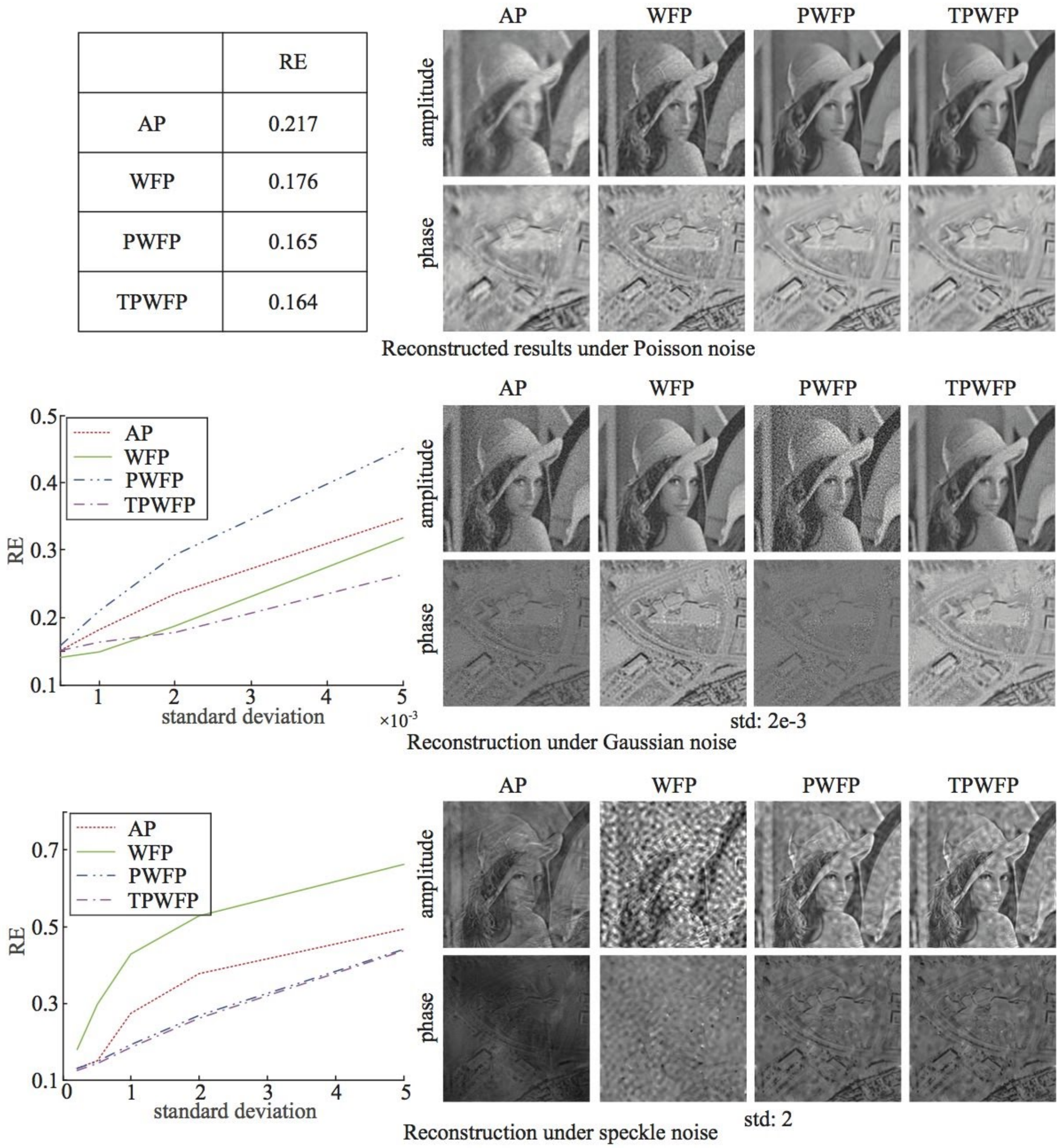


Figure 1. The FPM system and its image formation. This technique sequentially illuminates the sample with different incident angles, and correspondingly captures a set of low-resolution (LR) images of the sample. Assuming that the incident light is a plane wave and the imaging system is a low-pass filter, the LR images captured under different incident angles correspond to different spatial spectrum bands of the sample



	RE
AP	0.217
WFP	0.176
PWFP	0.165
TPWFP	0.164

Figure 2. Reconstruction results of several FP algorithms on synthetic data corrupted with measurement noise. From the results, we can see that under small Gaussian noise, WFP outperforms the other three methods. This is because WFP assumes global uniform noise for both low and high spatial frequencies, which is consistent with the corrupted noise model. Instead, PWFP and TPWFP assume that noise would be smaller for lower intensities (especially for LR images correspond to high spatial frequencies). Thus, they cannot remove enough noise for these spatial frequencies and produce worse results. However, when noise grows to around std > 0.002, TPWFP get better results than WFP. This is because when noise is large, WFP cannot extract useful information from the noisy data, while TPWFP directly omits these measurements to avoid their negative influence on final reconstruction. For Poisson noise and speckle noise, while both PWFP and TPWFP obtains better results than the other methods, TPWFP is little advantageous than PWFP. This is because for these kinds of signal dependent noise, it is hard for the truncated gradient to correctly distinguish noise from latent signals.

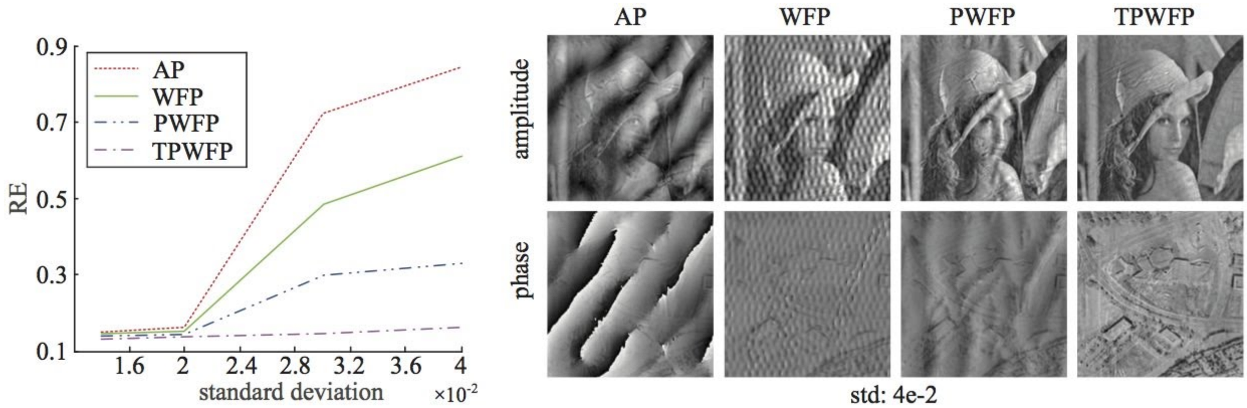


Figure 3. Reconstruction results by the three state-of-the-arts and the proposed TPWFP under pupil location error. From the results we can see that TPWFP outperforms state-of-the-arts a lot. This benefits from the nature of the utilized truncated gradient. In the thresholding operation, if one measurement (spatial space) is far from reconstruction due to pupil location error, we omit this measurement which represents misaligned information. Thus, we prevent the pupil location error from degenerating final reconstruction.

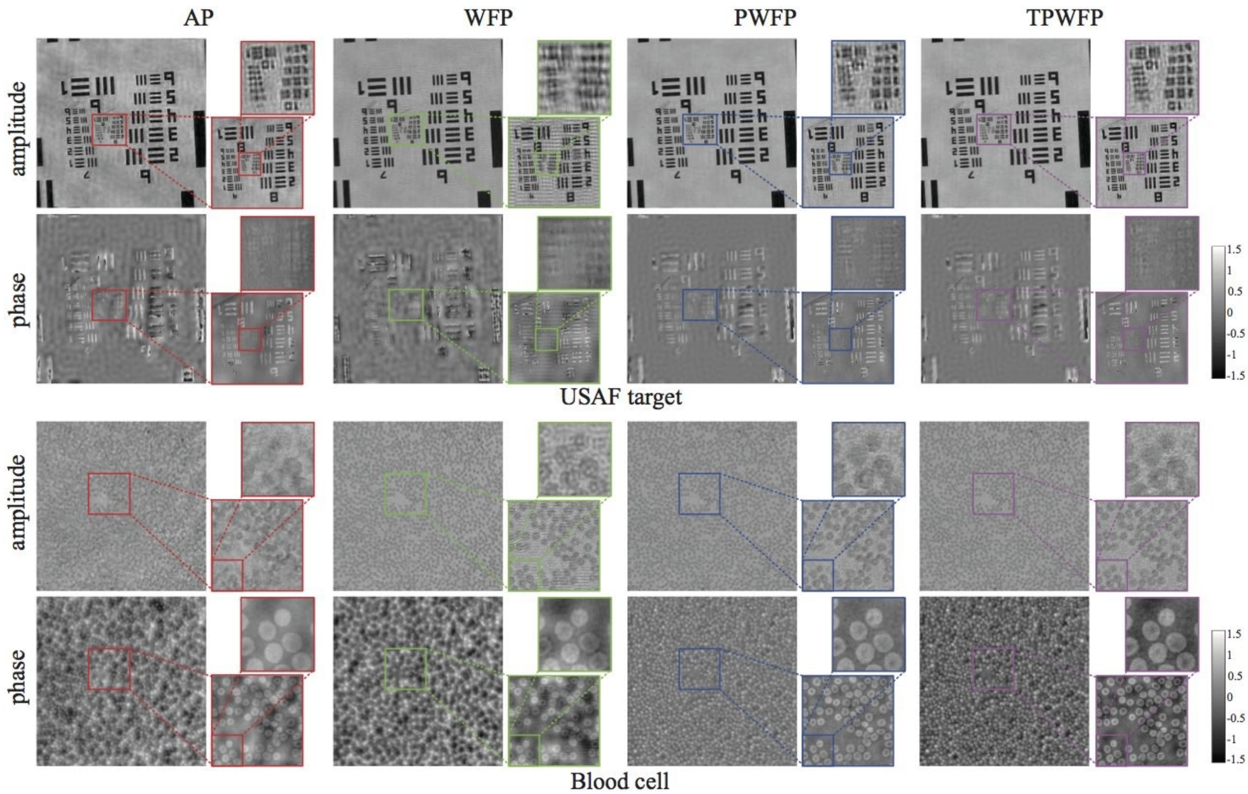


Figure 4. Reconstruction results of the FP algorithms on real captured data using our laser FPM setup. From the results we can see that AP produces intensity fluctuations in the background of reconstructed images (see the white background of the USAF target for clear comparison) and low image contrast (see the reconstructed amplitude of the red blood cell sample). WFP also obtains corrugated artifacts due to the speckle noise produced by the laser illumination. Both PWFP and TPWFP obtain better results than AP and WFP, while TPWFP produces results with more image details (see the reconstructed amplitude of the USAF target, especially group 10) and image contrast (see the reconstructed phase of the red blood cell sample) than PWFP. To conclude, TPWFP outperforms the other methods with less artifacts, higher image contrast and more image details.

Publications

Liheng Bian, Jinli Suo, Jaebum Chung, Xiaoze Ou, Changhuei Yang, Chen Feng, and Qionghai Dai, 'Fourier ptychographic reconstruction using Poisson maximum likelihood and truncated Wirtinger gradient,' Scientific Reports, 2016.

Materials

(coming soon) SCIENTIFIC REPORTS nature (coming soon)

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Author contributions statement

L.B. and J.S. proposed the idea and conducted the experiments. J.C. and X.O. built the setup. L.B., J.S., J.C. and X.O. wrote and revised the manuscript. J.S., C.Y., F.C. and Q.D. supervised the project. All the authors reviewed the manuscript.

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