LENSLESS PHASE RETRIEVAL WITH REGULARIZATION BY BLIND NOISE MAP ESTIMATION AND DENOISING

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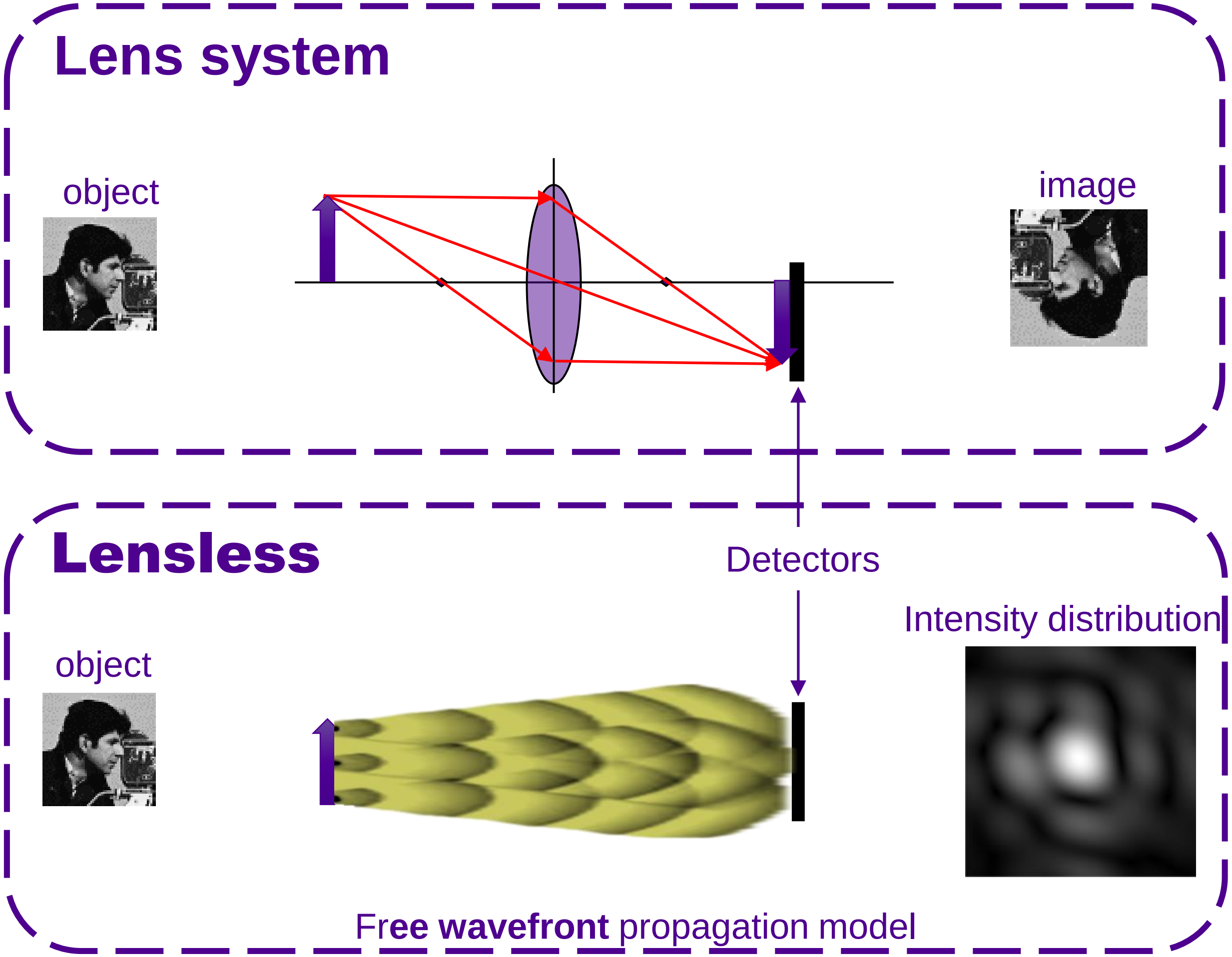
Outline

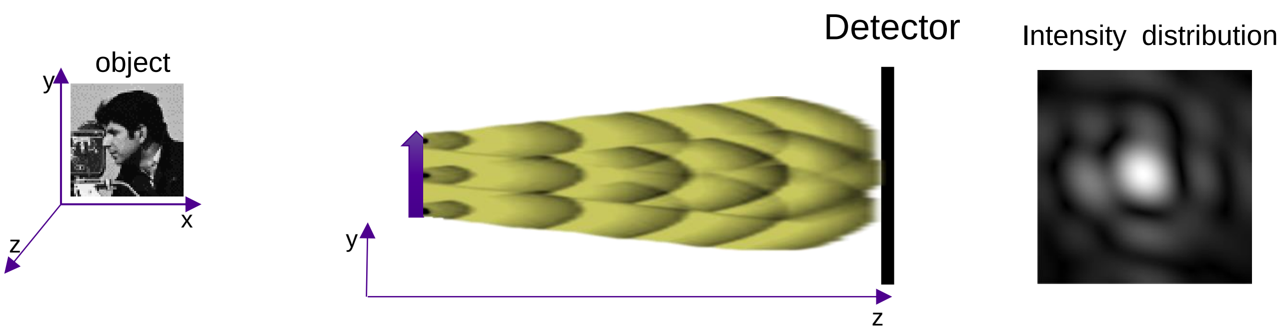
- **Introduction**
  - Lensless imaging
  - Phase problem and its solution
  - Noise in real life setup
  - Blind noise map estimation and denoising, PIXPnet
- **Developed algorithm**
- **Results**

Lensless imaging

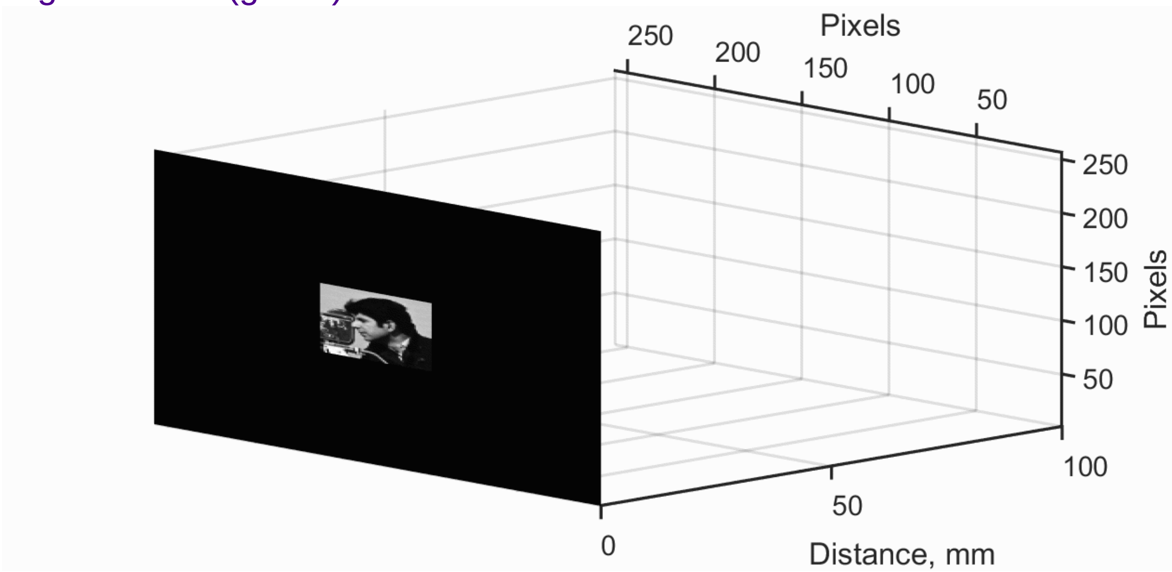
Lensless wave propagation



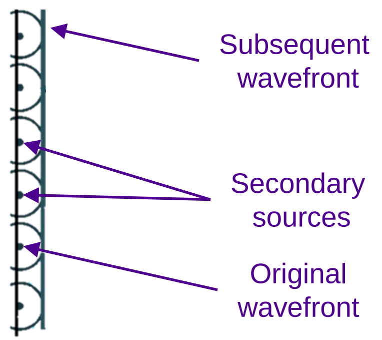
Lensless wave propagation

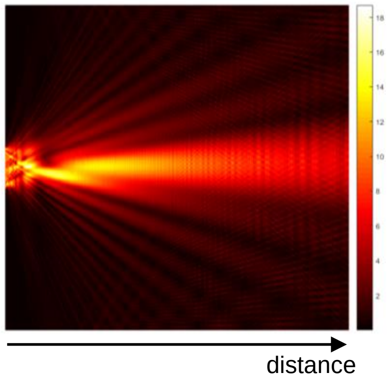


Single wavelength 540 nm (green)



Propagation model





The Rayleight-Sommerfeld integral solution in the **Angular spectrum** model is used:

$$u_s(x,y) = \mathcal{F}^{-1}\left[H(f_x,f_y,z)\cdot\mathcal{F}\{u_0(x,y)\}\right]$$

$$H(f_x,f_y,z) = \begin{cases} exp\left[i\frac{2\pi}{\lambda}z\sqrt{1-\lambda^2(f_x^2+f_y^2)}\right], & f_x^2+f_y^2 \le \frac{1}{\lambda^2}, \\ 0 & , \ otherwise \end{cases}$$

Where u_o – object wavefront, u_s – propagated object wavefront, $\mathcal{F}$ and $\mathcal{F}^{-1}$ stay for the Fourier and inverse Fourier transforms, z is a propagation distance, f_x and f_y are spatial frequencies, λ – wavelength.

Phase problem and solution

The **phase problem** is the name given to the problem of loss of information concerning the **phase** that occurs when making a physical measurement.

$$u = A(x,y)e^{i\varphi(x,y)}$$

A(x,y), object's amplitude

$\varphi(x,y)$, object's phase

Registration

Registration

$$I(x,y) = |A_d(x,y)|^2$$

Reconstruction

$$A(x,y) = \sqrt{I(x,y)}$$

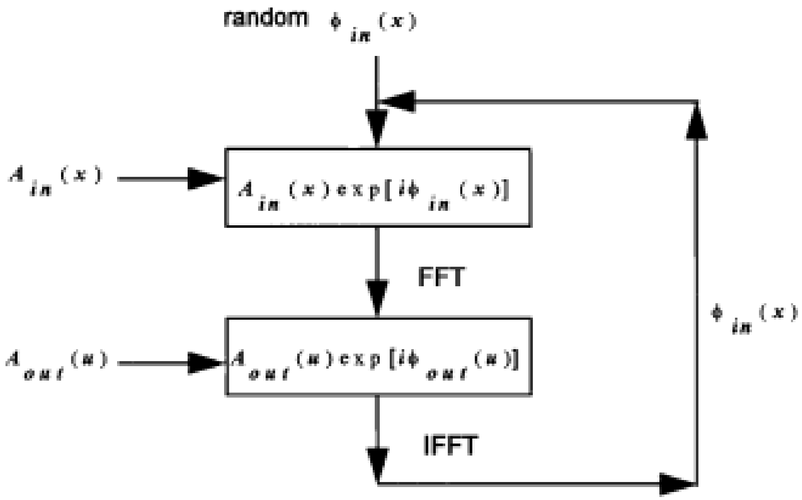
??

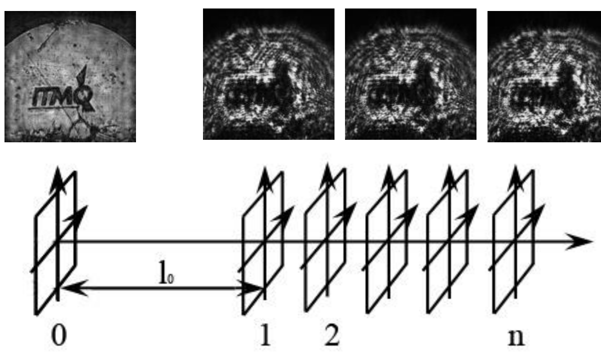
Phase retrieval is the process of algorithmically finding solutions to the **phase problem**.

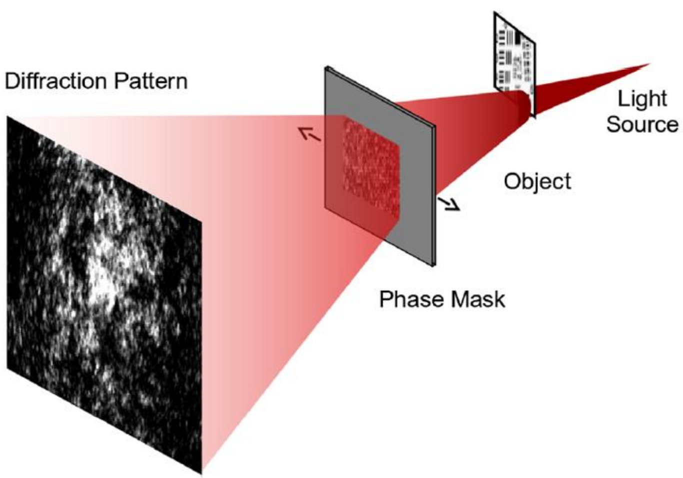
Phase problem and solution

Object plane

Sensor plane

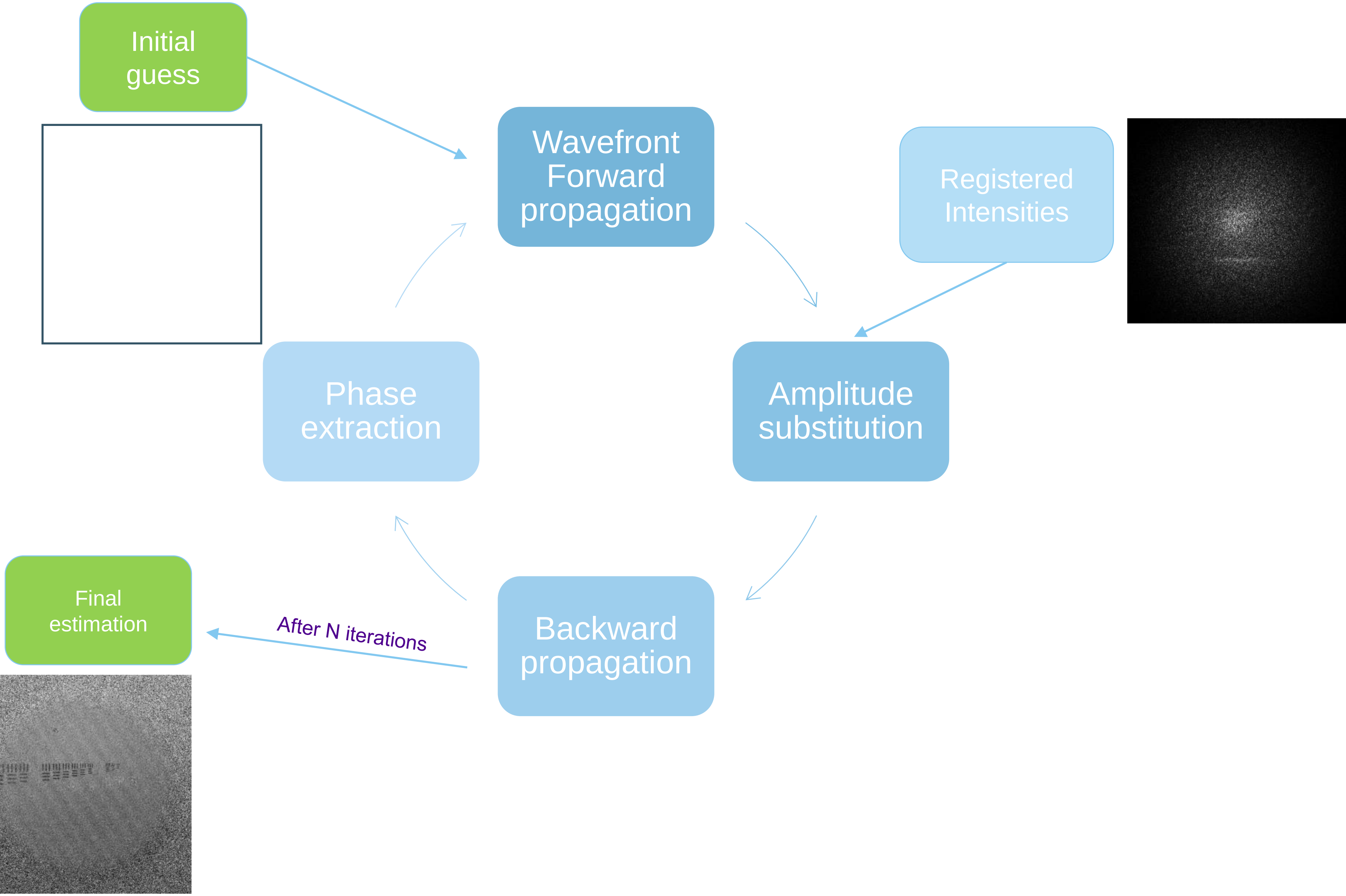






Different registration planes
Different wavelengths
Different illumination

Typical phase retrieval algorithm



Noise in reconstructions

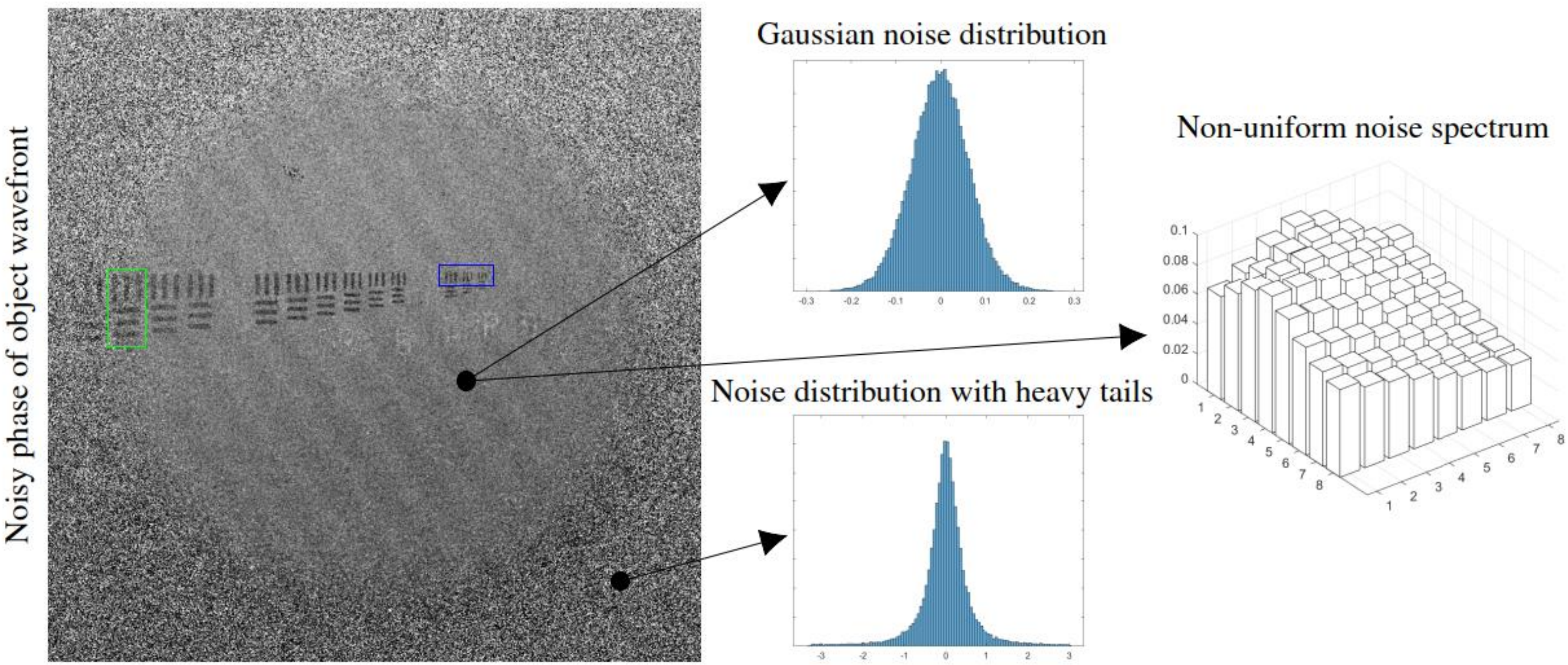
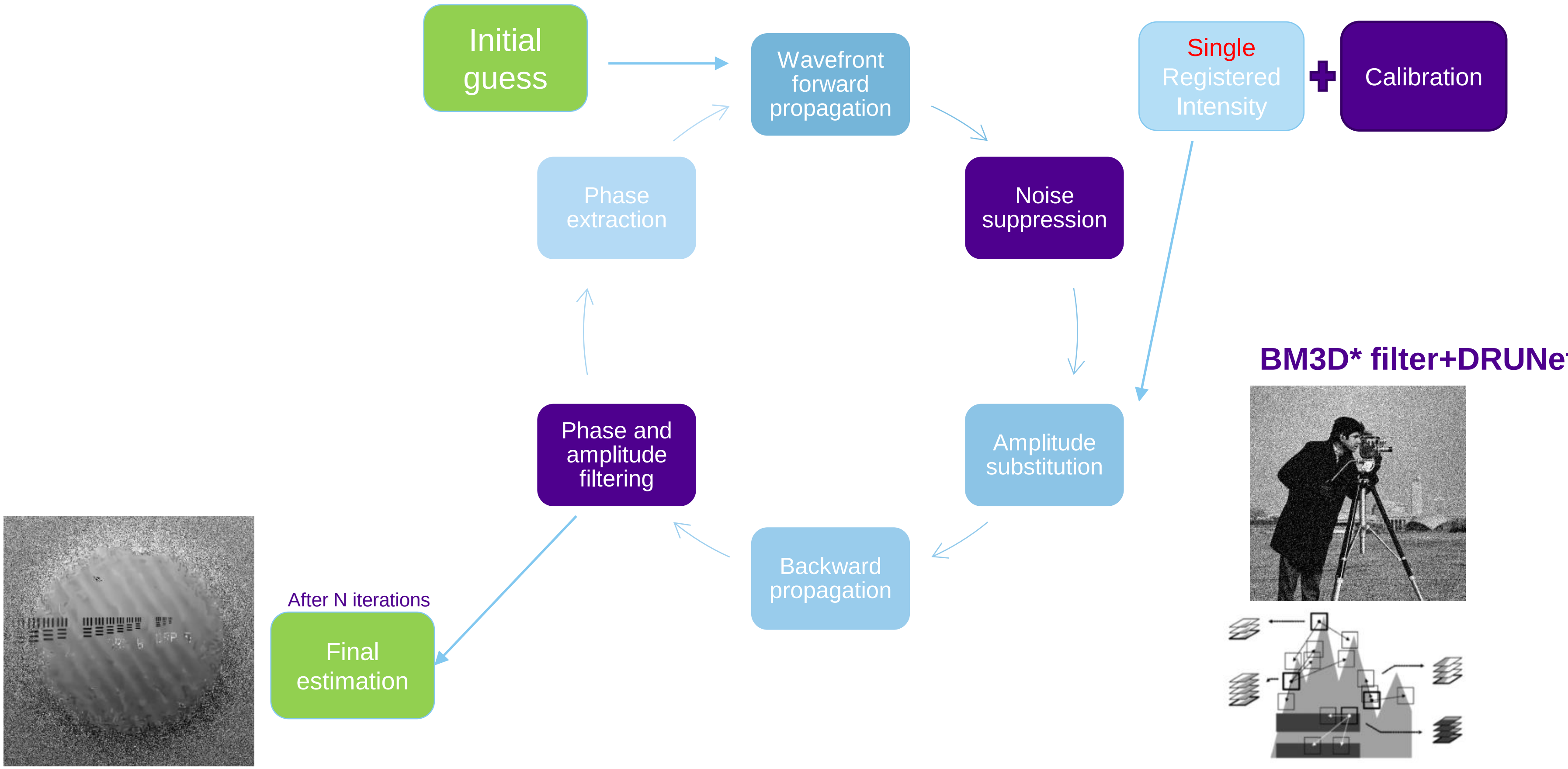


Fig. 1. Phase image with mixed noise characterized by non-stationary spectrum, different levels, and spatial distributions. Histograms demonstrate these distributions from middle and border locations: top and bottom, respectively. From the right, the 3D plot is 8×8 DCT spectrum of the noise for the central part of the phase image. Blue and green rectangles on the image outline regions for reconstruction quality estimation.

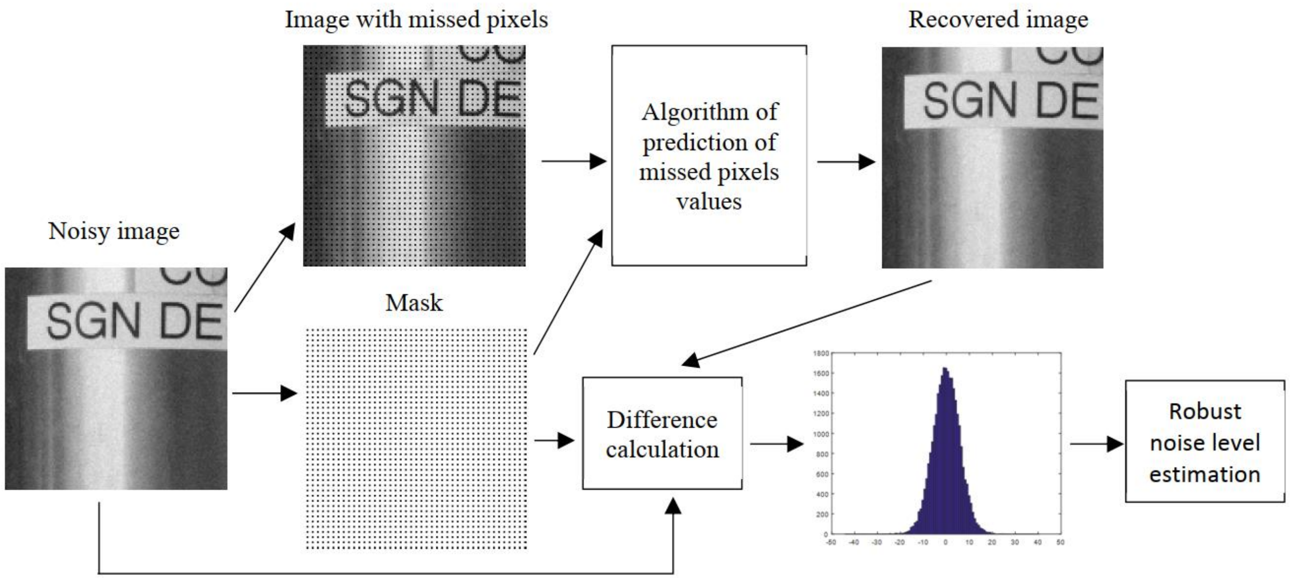
Single shot phase retrieval



*Y. Mäkinen, L. Azzari and A. Foi, "Collaborative Filtering of Correlated Noise: Exact Transform-Domain Variance for Improved Shrinkage and Patch Matching," in IEEE Transactions on Image Processing, vol. 29, pp. 8339-8354, 2020

Solution for noise estimation

PIXPnet



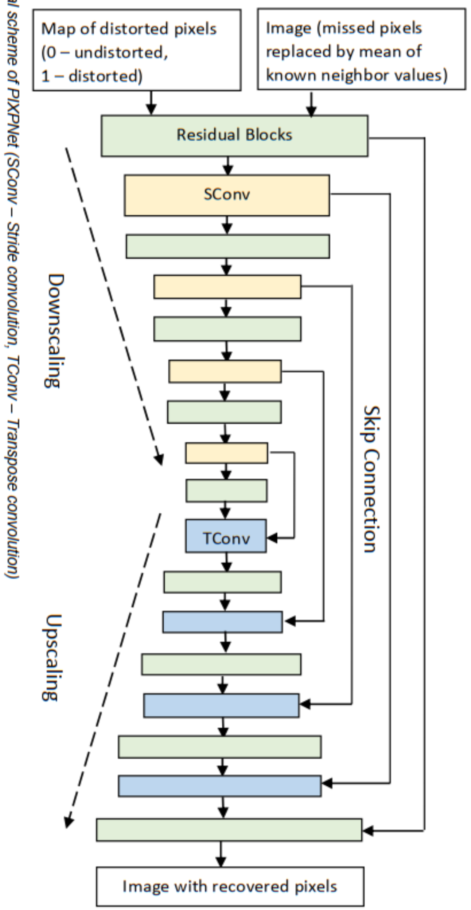


Fig. 3. Structural scheme of PIXPNet (SConv – Stride convolution, TConv – Transpose convolution)

γ	Noisy	PIXPNet prediction	DRUNet	Proposed, iteration 2
5	19.2	25.3	20.5	29.4
7	17.8	24.6	19.4	28.5
10	16.3	23.7	18.4	27.4
15	14.7	22.7	17.4	26.2
20	13.5	21.9	17.0	25.2

Table 1. Suppression of noise with Cauchy distribution, Tampere17 image set, PSNR, dB

M Ponomarenko, O Miroshnichenko, V Lukin, K Egiazarian , "Blind estimation of noise level based on pixels values prediction" in Proc. IS&T Int'l. Symp. on Electronic Imaging: Computational Imaging, 2022, pp 152-1 - 152-5

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PIXPnet

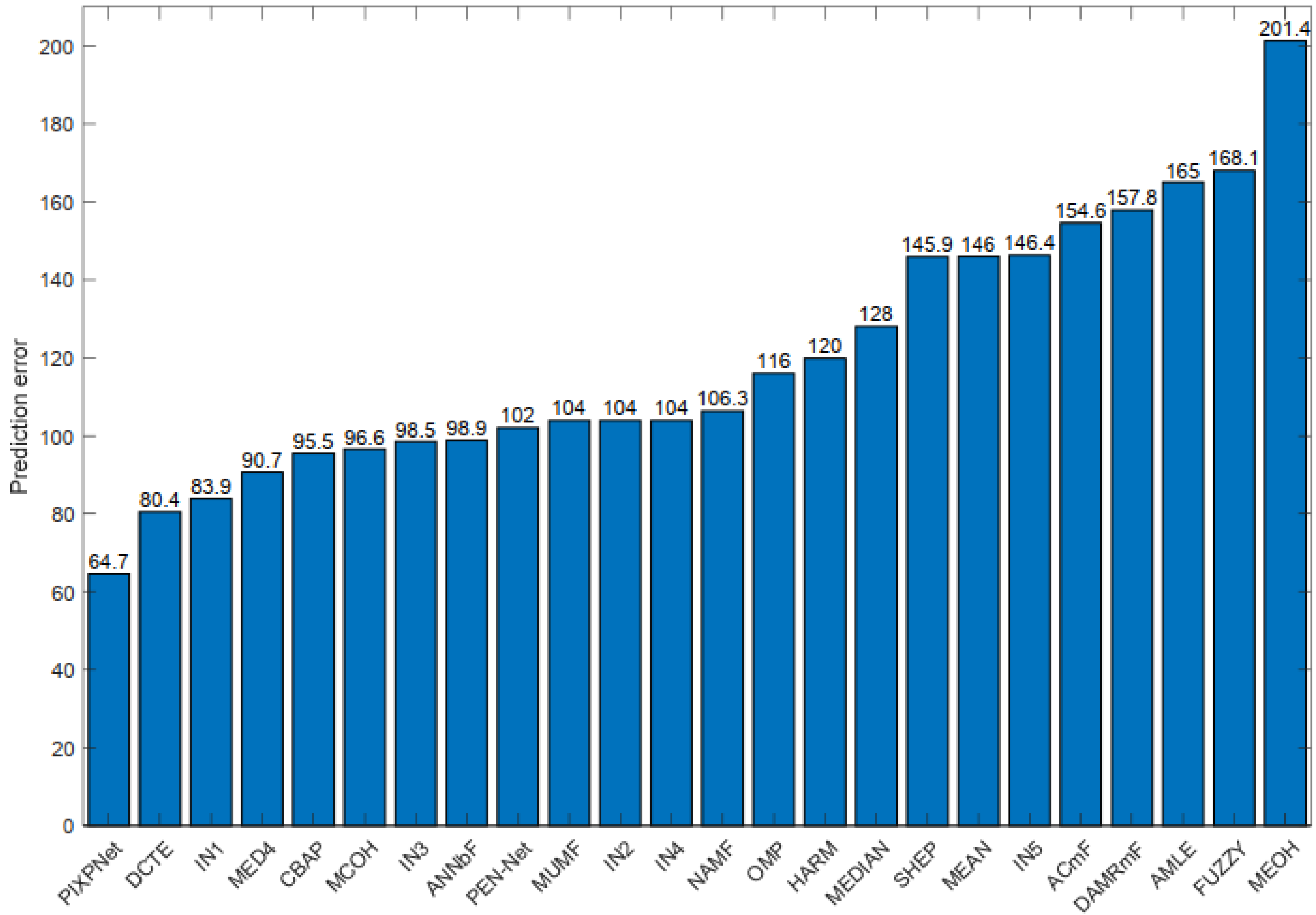
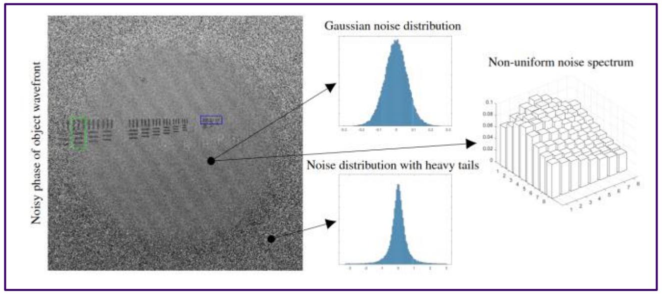


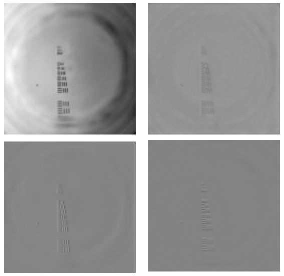
Fig. 4. Prediction errors for pixels recovering by different methods

M Ponomarenko, O Miroshnichenko, V Lukin, K Egiazarian , "Blind estimation of noise level based on pixels values prediction" in Proc. IS&T Int'l. Symp. on Electronic Imaging: Computational Imaging, 2022, pp 152-1 - 152-5

Proposed algorithm

Proposed algorithm





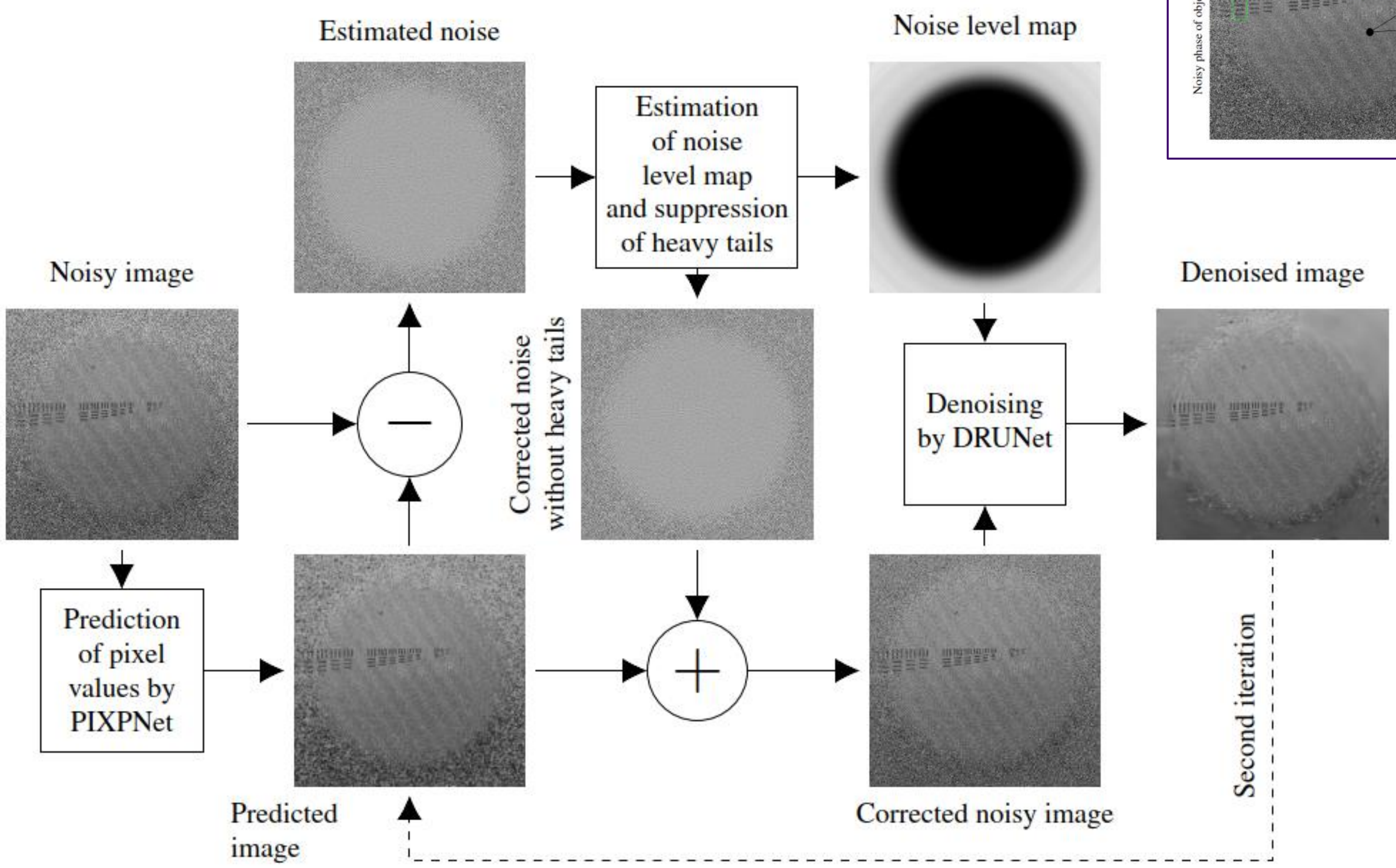


Fig. 2. Simplified flow chart of the proposed denoising. Follow arrows from left to right: from noisy image to denoised one.

Results

Results

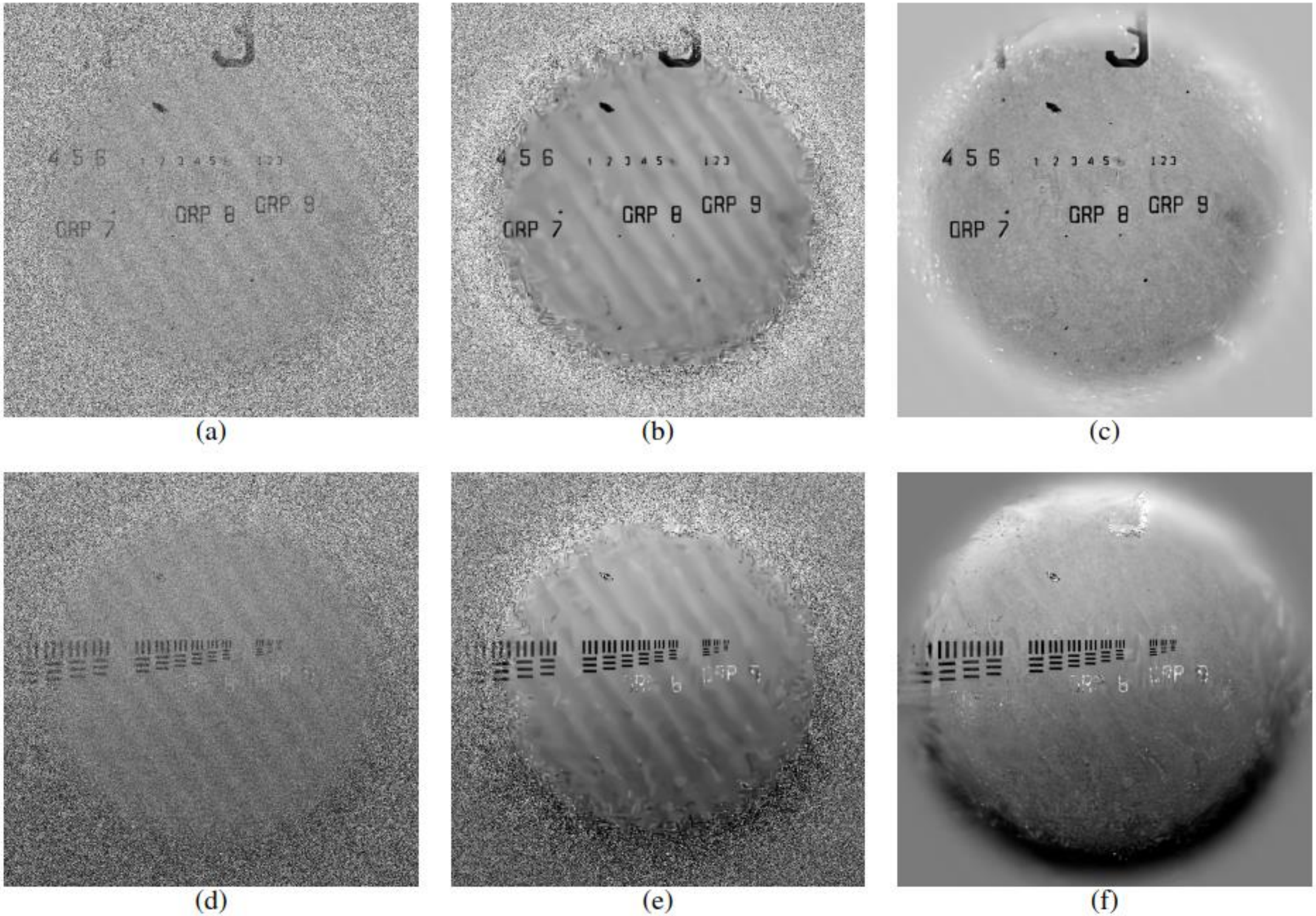


Fig. 3. Visual comparison: (a) noisy amplitude, (b) amplitude denoised by previous algorithm, (c) amplitude denoised by the proposed method, (d) noisy phase, (e) phase denoised by previous algorithm, (f) phase denoised by proposed method

Results

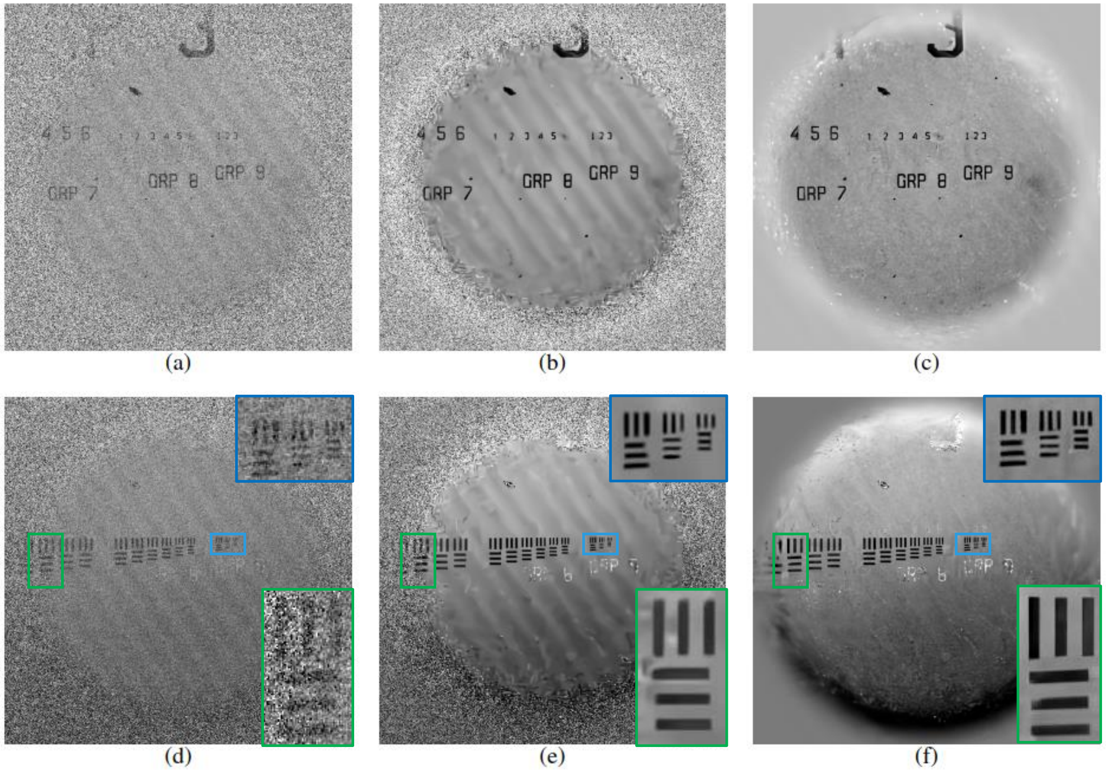
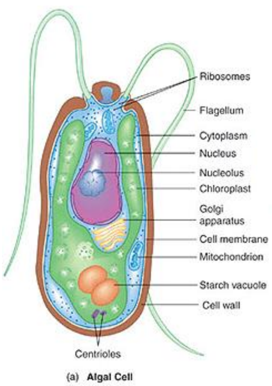


Fig. 3. Visual comparison: (a) noisy amplitude, (b) amplitude denoised by previous algorithm, (c) amplitude denoised by the proposed method, (d) noisy phase, (e) phase denoised by previous algorithm, (f) phase denoised by proposed method

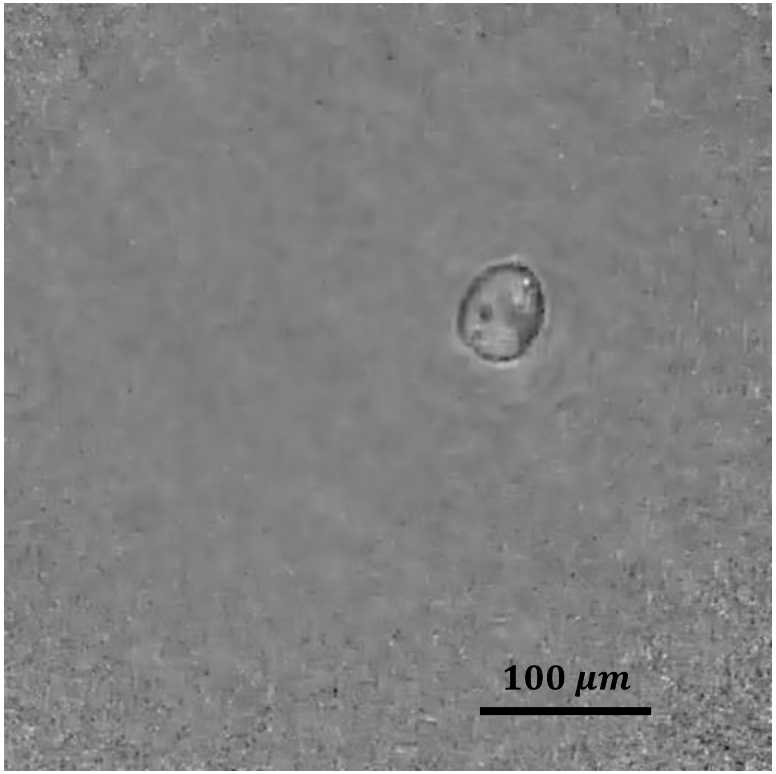
Region	Noisy phase	Previous denoising	Proposed denoising
first	110.8	106.5	66.3
second	99.0	69.2	51.4
both	104.9	87.8	59.3

Table 3. RMSE of height map estimation from the phase reconstructions, nm

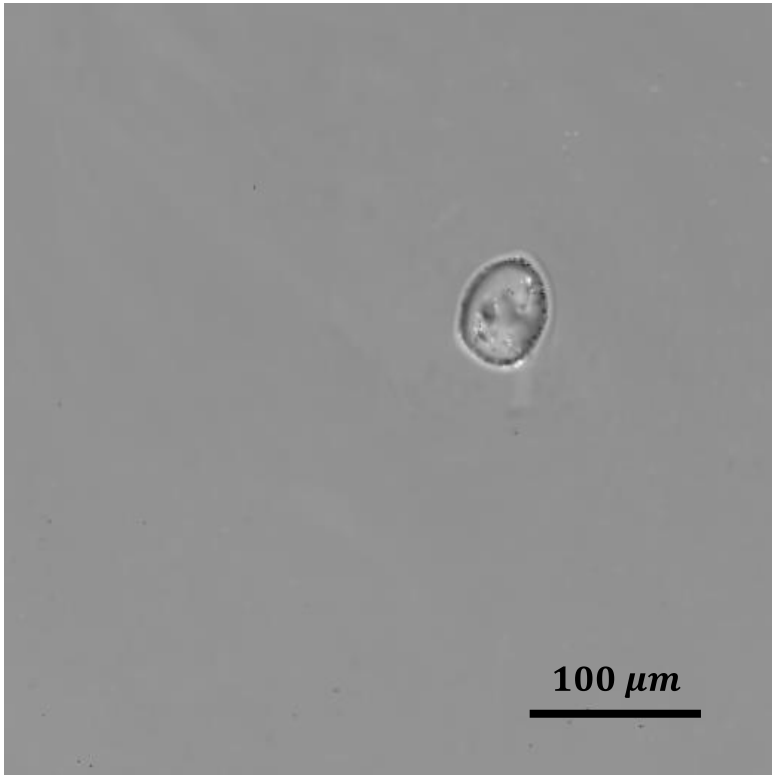
Physical experiments with dynamic object (moving single-celled eukaryote)



Previous approach phase



Filtered phase new



P. Kocsis, I. Shevkunov, V.Katkovnik, H.Rekola, and K. Egiazarian, Opt. Express 29, 43662-43678 (2021)

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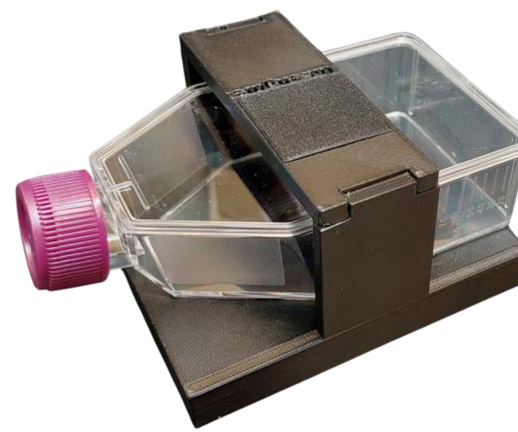
Conclusions

- New approach for real life noise suppression with heavy noise tails
- Lensless imaging is enhanced significantly in:
  - achieving more effective noise suppression
  - 40% enlarging field of view
  - >26% increase in accuracy of the height estimation



PROFI 6:TAU Imaging Research Platform

Thank you for your attention!

Questions and collaboration:

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