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Optimal spiral phase modulation in Gerchberg-Saxton algorithm for wavefront reconstruction and correction

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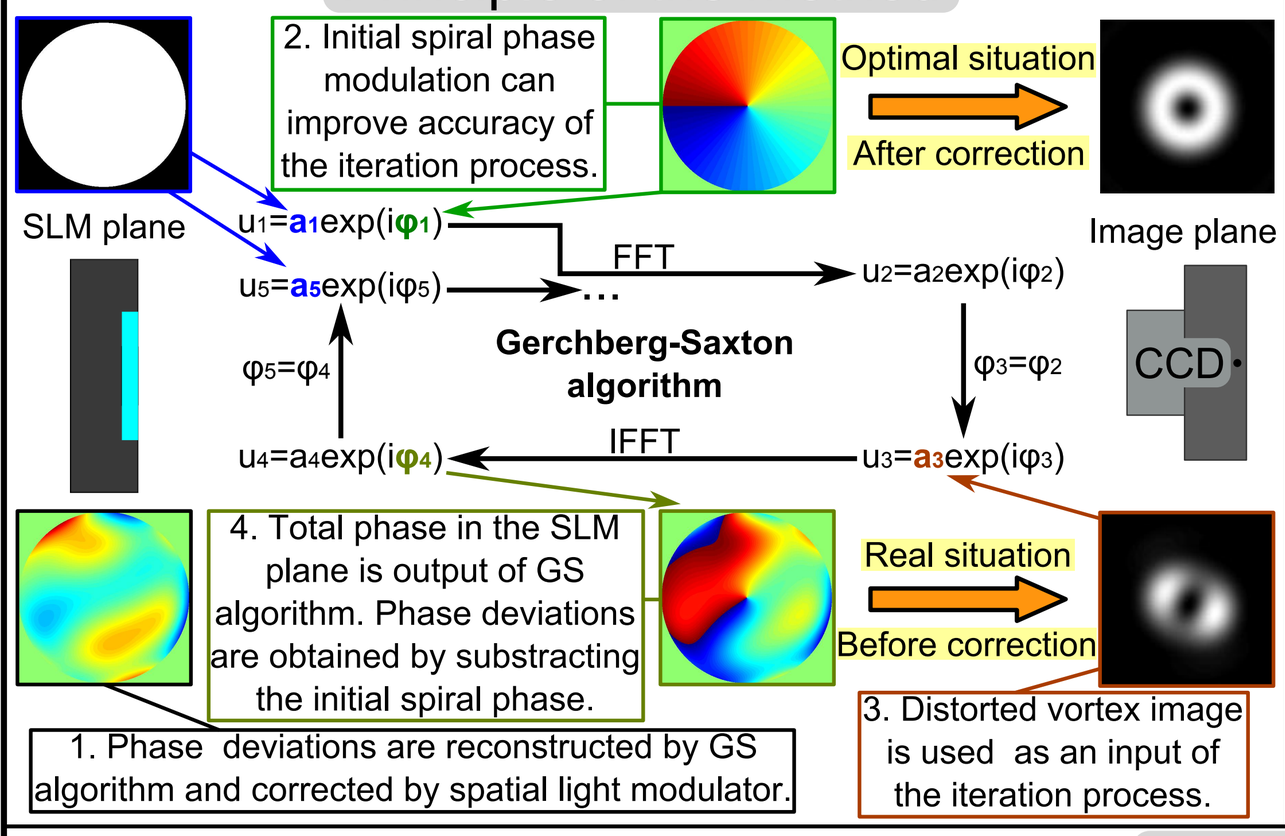
Introduction: In the phase retrieval applications, Gerchberg-Saxton (GS) algorithm is widely used for simplicity of implementation [1]. The GS algorithm can advantageously be deployed in combination with spatial light modulator (SLM) enabling simultaneous correction of optical aberrations. Recently it was demonstrated that the precision and efficiency of the aberration correction by the GS algorithm can be significantly enhanced by a vortex image spot used as the target intensity pattern in the iterative process [2]. In the previous works, the spiral phase mask generating optical vortex beam with the topological charge m=1 was recommended as an optimal choice providing high performance of the wavefront reconstruction and aberration correction [2, 3, 4]. Here we present a modification of the adaptive correction scheme based on the use of optical vortices with higher topological charges.

Principle of the method



Our optimization

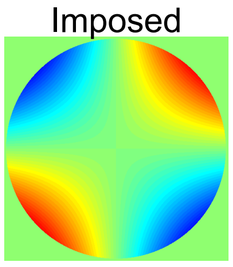
Aberration definition:

$\exp(ik\mathbf{W})$, $W=\sum_{j=1}^{J} z_j Z_j$, where Z are Zernike polynomials and z are Zernike coefficients [5] defined on:

- circular aperture (circle) Z_{Cj}, z_{cj}
- annular aperture (ring) Z_{Rj}, z_{rj}

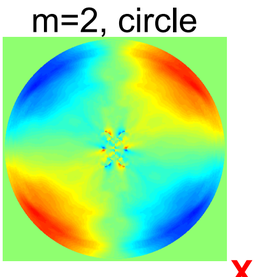
Zernike coefficients z_{cj} are used for aberration definition and iteration process evaluation ($z_{c5} = 0.15\lambda$).

Imposed



Accuracy of GS algorithm is impaired near singular point and faults are extended over whole circular aperture (m=2).

Retrieved m=2, circle

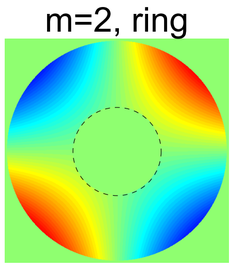


x

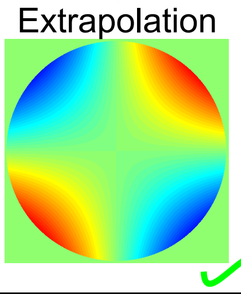
In our new model **annular aperture** is used as the input parameter of the algorithm (m=2).

Phase deviations over annular aperture are fitted by Zernike polynomials Z_{Rj} and distortions in the centre are obtained by z_{rj} to z_{cj} transformation.

Retrieved m=2, ring



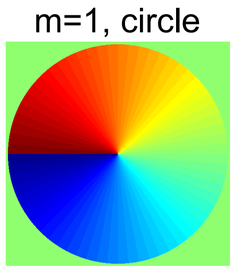
Extrapolation



Simulation

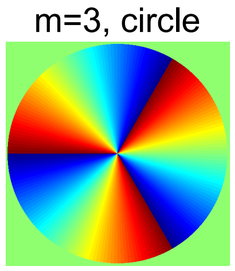
Initial spiral phase modulation

m=1, circle

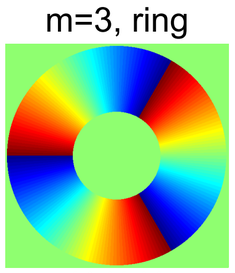


m=1, ring

m=3, circle

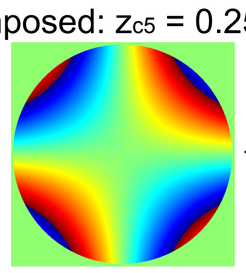


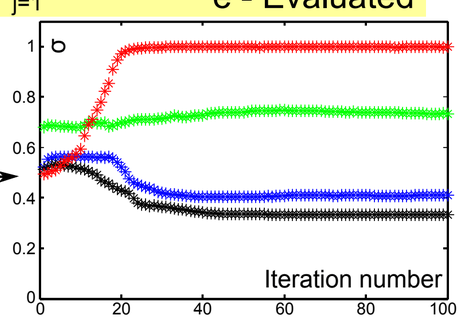
m=3, ring



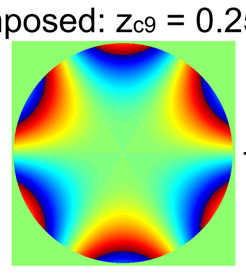
$\sigma=\sum_{j=1}^{J}|z_{cj}^{i}|^2/\left(\sum_{j=1}^{J}|z_{cj}^{i}|^2+\sum_{j=1}^{J}|z_{cj}^{i}-z_{cj}^{e}|^2\right)$, i - Imposed, e - Evaluated

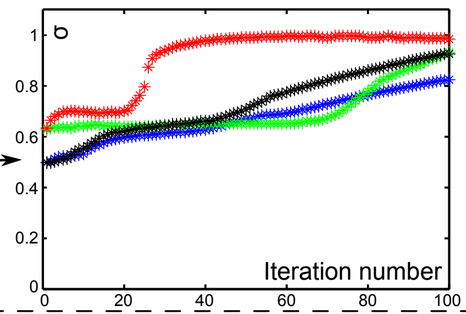
Imposed: $z_{c5} = 0.25\lambda$





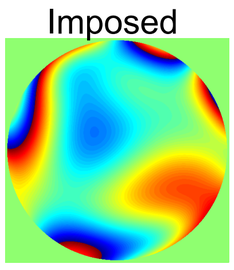
Imposed: $z_{c9} = 0.25\lambda$



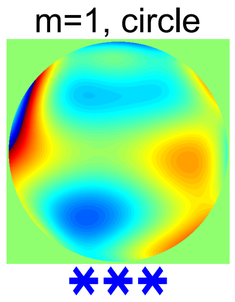


Imposed and evaluated phase distortions after 100 iterations

Imposed



m=1, circle



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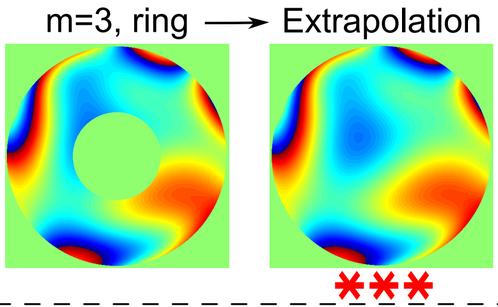
m=3, ring ⟶ Extrapolation



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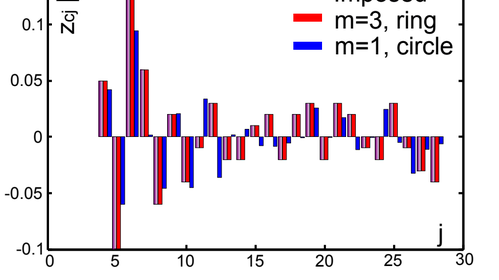
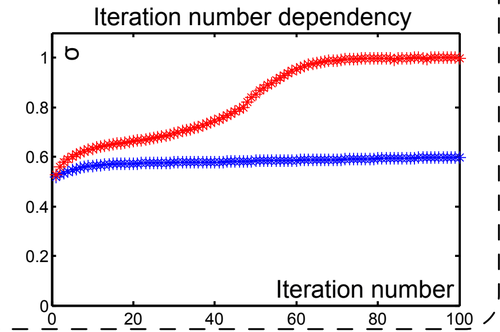
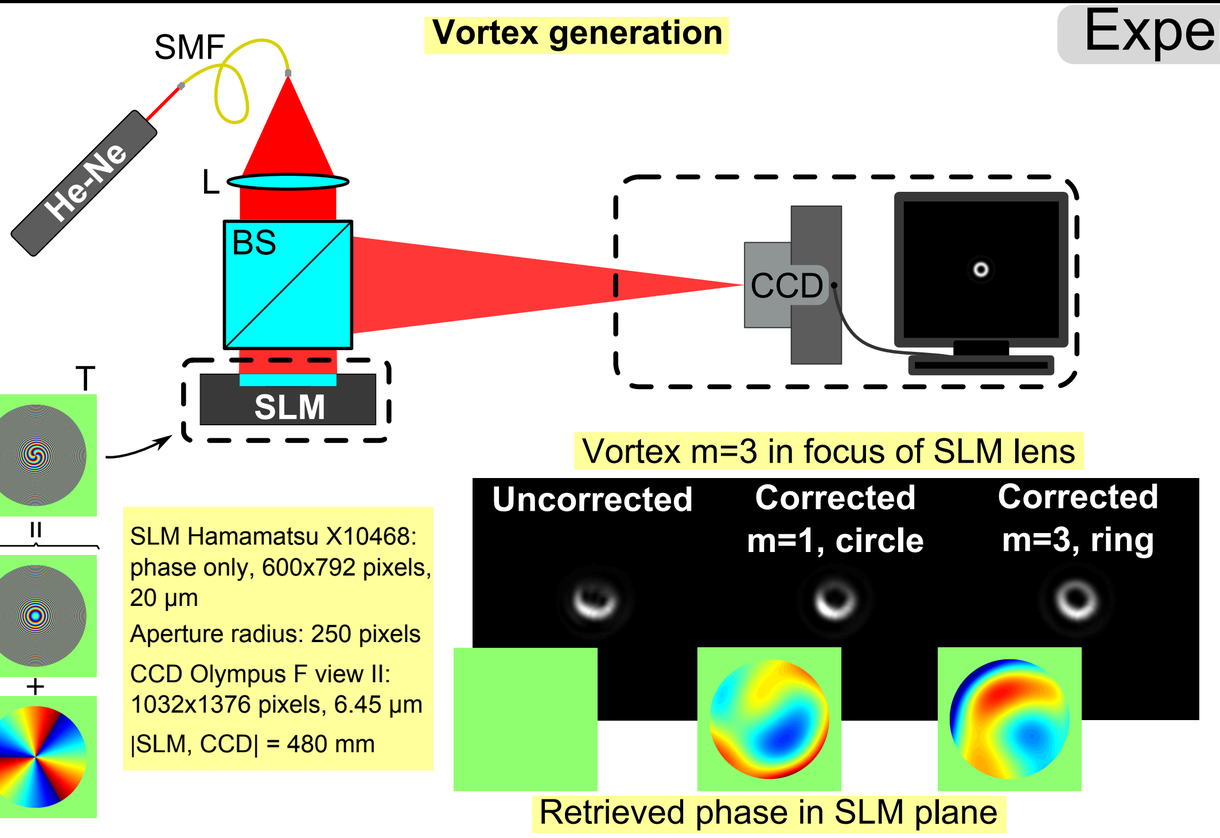




Experiment

Vortex generation



SLM Hamamatsu X10468: phase only, 600x792 pixels, 20 μm

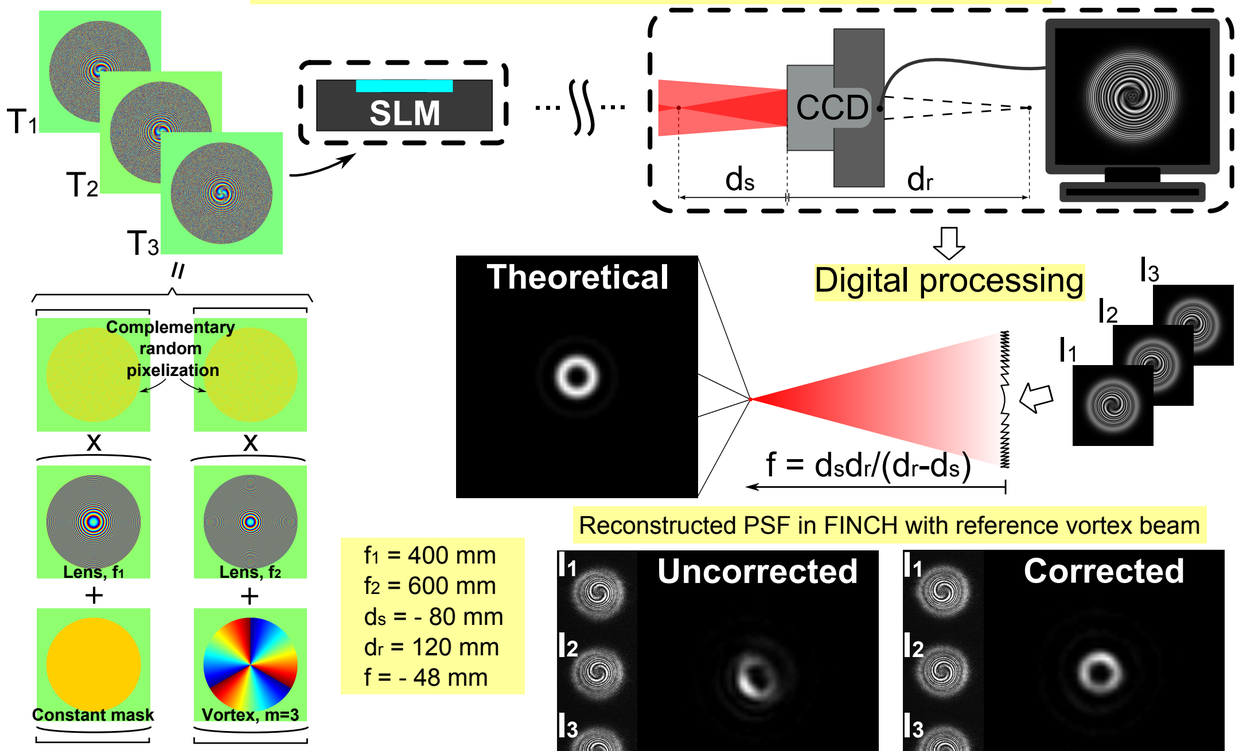
Aperture radius: 250 pixels

CCD Olympus F view II: 1032x1376 pixels, 6.45 μm

|SLM, CCD| = 480 mm

Application in digital in-line holography

Correction process: retrieved compensation phase is displayed on SLM



f1 = 400 mm
f2 = 600 mm
ds = - 80 mm
dr = 120 mm
f = - 48 mm

Reconstructed PSF in FINCH with reference vortex beam

Conclusion:

The efficient modification of the vortex based GS algorithm was proposed and used for adaptive compensation of phase deviations. Application potential of the method was demonstrated on the optimized vortex focusing by a SLM lens and the enhancement of the point spread function reconstructed in Fresnel incoherent correlation holography using reference vortex beam [6].

References:

[1] R.W. Gerchberg, and W.O. Saxton, A practical algorithm for the determination of phase from image and diffraction plane pictures, Optik 35, 237246 (1972).

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[5] D. Malacara, Optical shop testing, Wiley (2007).

[6] P. Bouchal, and Z. Bouchal, Selective edge enhancement in three-dimensional vortex imaging with incoherent light, Opt. Lett. 37, 2949-2951 (2012).

Acknowledgement:

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