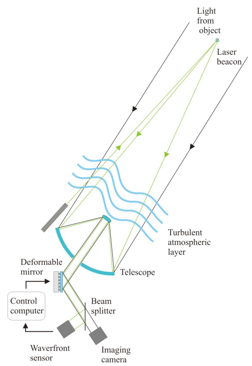
Speckle-Averaging Phase Conjugative Adaptive Optics

Ernst Polnau and Mikhail A. Vorontsov

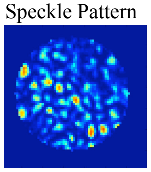
Introduction

Conventional phase conjugative adaptive optics is a technique to correct wavefront aberrations introduced by atmospheric turbulences in the optical path of an optical setup. Typical for such a system is e.g. an astronomical telescope where a laser beam is used to produce a laser beacon on the sky and the returned light from this beacon is picked up by the telescope and the phase aberrations then measured by a wavefront sensor. The measured phase is then used to calculate settings for the actuators of a deformable mirror which tries to cancel the phase aberrations introduced by the turbulent atmosphere.

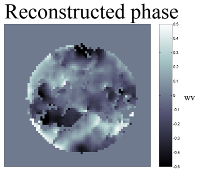


This technique works well as long as the atmospheric turbulences are in the near field of the optical aperture and no intensity scintillations are present. Problems exists when the turbulent atmospheric layer is not close to the aperture or if the turbulence is extended along the whole optical path, e.g. for horizontal paths. In this case intensity scintillations and speckle patterns are present in the aperture of the optical instrument. In particular speckle patterns cause problems since reconstructing the wavefront from the data of the wavefront sensor results in branch points and discontinuities in the reconstructed wavefront limiting the performance of the closed-loop adaptive optics system.

Speckle Pattern

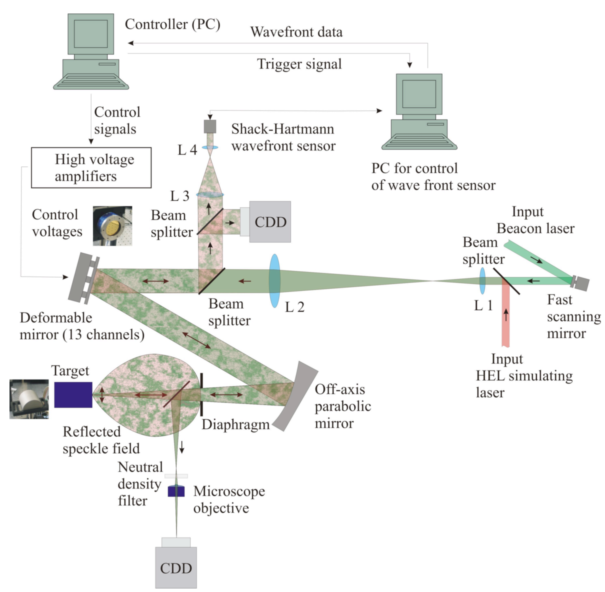


Reconstructed phase



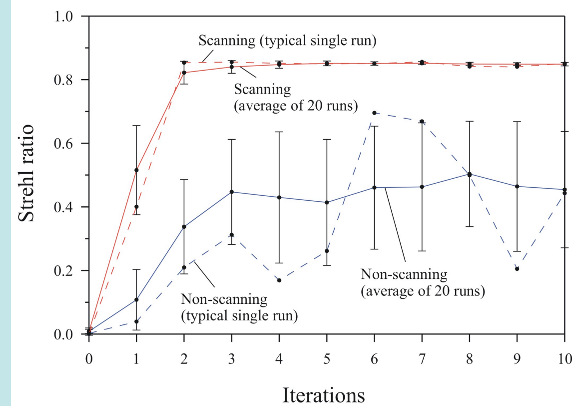
A possible solution to overcome these problems is to use the technique of speckle-averaging. In this technique either a moving target with a rough surface or a scanning laser beacon beam is used to produce fast changing speckle pattern and therefore fast moving branch points and discontinuities. Since the speckle patterns change fast compared to the integration time of the wavefront sensor, the branch points and discontinuities are effectively filtered out in the wavefront determined by the wavefront sensor.

Experimental Setup



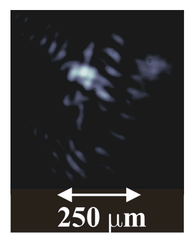
The schematic shows the setup used to evaluate the use of speckle averaging technique in closed-loop adaptive optics systems. The input beacon beam laser (532nm) with a diameter of 10 mm is reflected by the fast scanning mirror and transmitted trough two lenses L1 and L2 which form an optical relay and which expand the laser beam to a diameter of 25 mm. This expanded beam falls on a 13 channel deformable mirror. From this deformable mirror the beam is reflected towards an off-axis parabolic mirror. The parabolic mirror focuses the beam on an alumina target with a rough surface. From the target a speckle pattern is reflected. Part of the light of this speckle pattern is reflected back trough the optical system towards a beam splitter between the deformable mirror and the relay lens L2. From this beam splitter the light is reflected through a second optical relay (lenses L3 and L4) towards the wavefront sensor. A second beam splitter redirects part of the light to a CCD camera. A red laser (632nm) is feed into the optical path after the scanning mirror and is used to simulate either the high energy laser (HEL) in directed energy applications or the signal beam in laser communication systems. Also a beam splitter is installed close to the target surface to produce a second focal spot which can be closely inspected by combination of a microscope-objective and a CCD camera.

Results

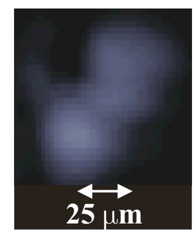


The diagram shows the Strehl ratio - a measure for the quality of a focused laser spot – vs. the number of iterations for conventional and speckle-scanning closed-loop adaptive control. The achieved Strehl ratios and the stability are higher for speckle averaging.

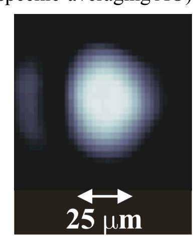
Before optimization (random aberrations)



After optimization (conventional AO)



After optimization (speckle-averaging AO)



Images of the laser spot before and after closed-loop adaptive optimization taken with the combination of microscope-objective and CCD camera. The speckle-averaged optimization results in the brightest target hot spot.