PROPAGATION OF ABERRATED BEAM THROUGH ATMOSPHERIC TURBULENCE

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ABSTRACT

Atmospheric turbulence is a major source of aberrations that may degrade the signal quality of a light beam that propagates through the atmosphere. Aberrations due to atmospheric turbulence is usually represented by Kolmogorov aberrations. In this work we consider a laser beam aberrated with a certain Zernike mode aberration. The beam is then incorporated Kolmogorov aberrations in order to represent the effect of atmospheric turbulence. We then measure the magnitude of the Zernike mode as the beam is incident on a modal wavefront sensor. We thus investigate how the various Zernike modes present in the beam are detected even after it passes through atmospheric turbulence. The experimental results are obtained by using a setup comprising two liquid crystal spatial light modulators (LCSLMs) implementing a computer generated holography technique.

OBJECTIVE

Investigation on how the various Zernike modes present in the beam are affected as it passes through atmospheric turbulence.

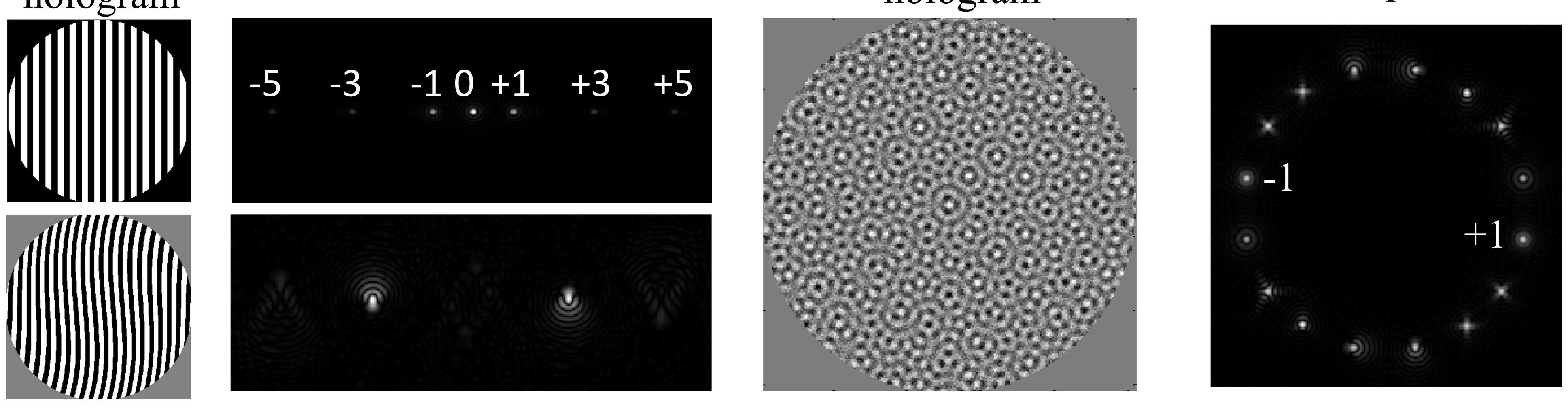
INTRODUCTION

- Atmospheric turbulence is a complete random process and can be represented by Kolmogorov aberrations..
- Kolmogorov phase screen can be generated in the lab environment with the help of Zernike polynomials.
- Atmospheric turbulence degrade the signal quality of a light beam that propagates through the atmosphere.
- The amount the Zernike modes present in the incident beam can be measured by a wavefront sensor (in our case a modal Wavefront sensor).

IMPLIMENTATION OF MODAL WAVEFRONT SENSOR

Modal wavefront sensor is a type of wavefront sensor in which the wavefront is described by decomposing it into a set of orthogonal polynomials and test the presence of each polynomials.

Incident Wavefront, $\psi(r,\theta) = \sum_{k=0}^{\infty} a_k Z_k(r,\theta)$ $\quad$ $Z_k(r,\theta)$ is the k[th] order Zernike mode



Implementation of binary hologram in modal wavefront sensing:
- +1 → Phase profile of the object beam → Positive bias
- -1 → Complex conjugate of +1 order → Negative bias

Positive bias and Negative bias → Intensity Difference

KOLMOGOROV PHASE SCREEN

Any arbitrary radial phase can be described as

$$\phi(\rho,\theta) = \sum_{n=0}^{\infty}\sum_{m=0}^{n} A_{nm} Z(\rho,\theta)_{nm}$$

Where, $Z(\rho,\theta)_{nm}$ are the Zernike polynomials and A_{nm} are the weightage factors

Noll matrix,

$$I_{nm} = \frac{0.15337(-1)^{n-m}(n+1)\Gamma(14/3)\Gamma(n-5/6)}{\Gamma(17/6)^2\,\Gamma(n+23/6)}$$

Variance, $\sigma_{nm}^2 = I_{nm}\left(\frac{D}{r_0}\right)^{5/3}$

D = the phase screen diameter

Turbulence coherence length, $r_0 = 1.68(C_n^2 L k^2)^2$

Here, $C_n^2 \approx 10^{-15}\ \mathrm{m}^{-2/3}$ (high turbulence condition)
$\approx 10^{-18}\ \mathrm{m}^{-2/3}$ (low turbulence condition)

L is the path length through the turbulent atmosphere

and- $k = \frac{2\pi}{\lambda}$, λ is the wavelength of the light

How to find the values of A_{nm}

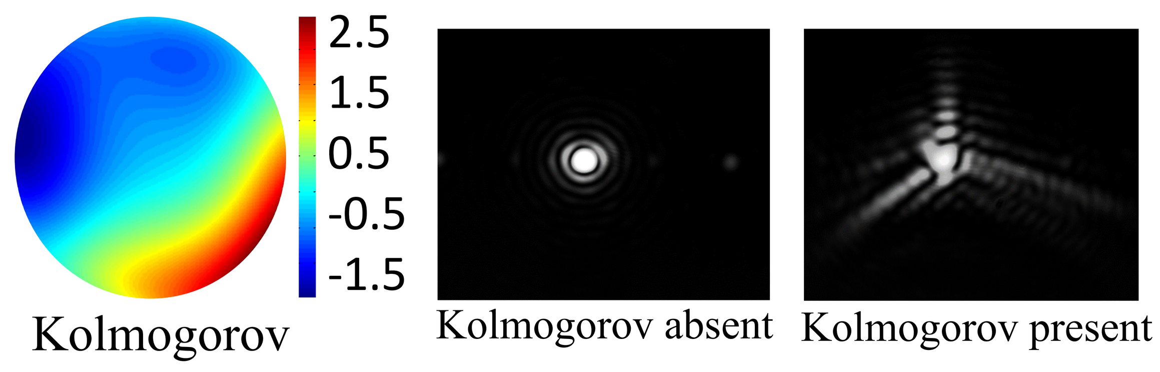
Calculate the value of I_{nm} and σ_{nm}

↓

A random distribution with zero mean and standard deviation of σ_{nm} is created

↓

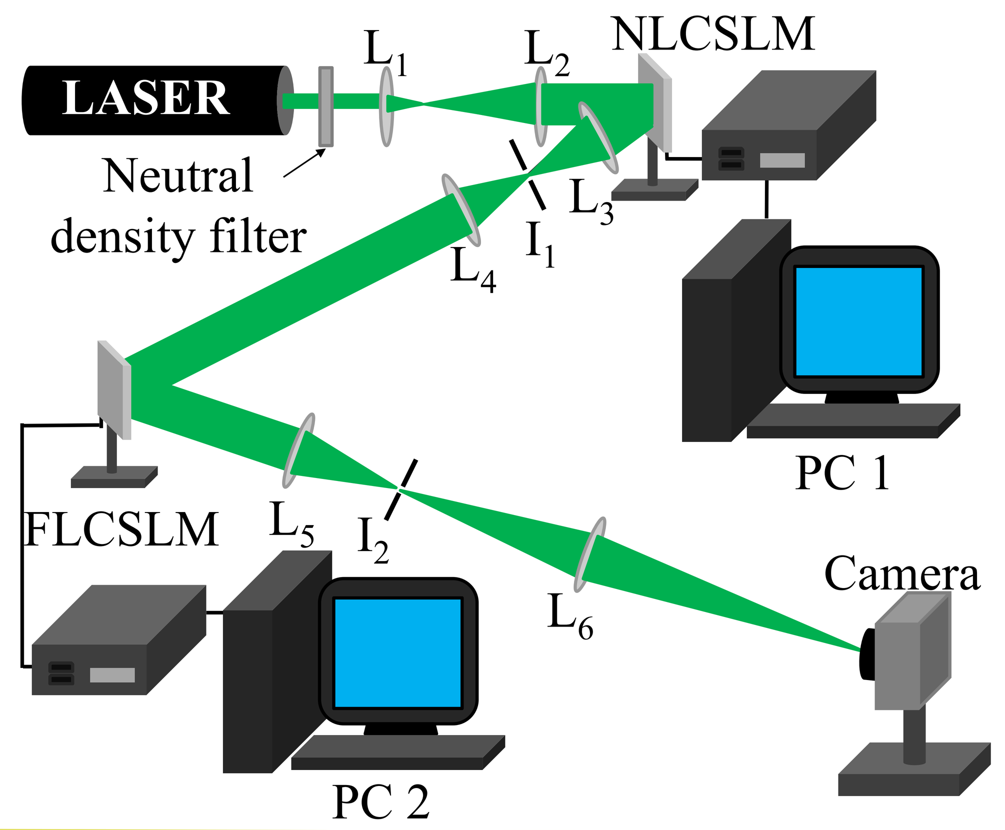
This gives us the random values of A_{nm}



Kolmogorov phase screen

Focal spot on the camera screen

EXPERIMENTAL SETUP



EXPERIMENTAL RESULTS

Z4 sensor									
Turbulence strength	RMS value of input mode	Applied Zernike mode							
		Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
No turbulence	+2	0.2018	0.0011	0.0047	-0.0585	-0.0913	0.0080	0.0008	-0.4522
	-2	-0.1701	0.0027	0.0031	0.0460	0.1168	0.0102	0.0124	0.4747
D/r_0 = 22.9289	+2	0.0685	-0.0071	0.0101	0.0304	-0.0510	0.0281	0.0124	-0.4484
	-2	-0.1468	0.0249	-0.0050	-0.0167	0.0582	-0.0167	0.0101	0.2090
D/r_0 = 45.8577	+2	0.1581	0.0397	-0.0397	-0.0425	0.0364	0.0494	0.0034	0.1976
	-2	-0.0770	0.0137	0.0523	0.2050	0.0094	-0.0044	0.0062	0.4133

Z8 sensor									
Turbulence strength	RMS value of input mode	Applied Zernike mode							
		Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
No turbulence	+2	0.0011	-0.0068	-0.0023	-0.0218	0.0270	-0.0195	-0.0296	-0.0229
	-2	-0.0095	-0.0069	-0.0072	-0.0066	-0.0832	-0.0170	-0.0070	0.2591
D/r_0 = 22.9289	+2	0.0034	0.0589	0.0078	-0.0694	0.0160	-0.0485	-0.0001	0.1653
	-2	0.0159	-0.0528	-0.0104	0.0293	-0.0033	0.0453	-0.0095	0.0874
D/r_0 = 45.8577	+2	0.2425	0.0025	0.0120	-0.0535	-0.0107	0.0989	-0.0130	0.2495
	-2	-0.0780	0.0536	0.0116	0.0985	0.2237	-0.0508	0.0828	0.6315

CONCLUSION

- A Kolmogorov phase screen is generated and is implemented to investigative the affect of the atmospheric turbulence on the various Zernike modes.
- The investigation is carried out with two sensors (Z_4 and Z_5), applying eight Zernike modes (Z_4 – Z_{11}) with RMS amplitude of +2 and -2 alternately.
- The Z_4 sensor is able to detect the presence of Z_4 mode in the incident beam, being less sensitive to the other modes except Z_{11}.
- The Z_8 mode is observed to be highly affected by the atmospheric turbulence so the Z_8 sensor is unable to detect the presence of Z_8 mode effectively.

REFERENCES

1. Burger, Liesl, Igor A. Litvin, and Andrew Forbes. "Simulating atmospheric turbulence using a phase-only spatial light modulator." South African Journal of Science 104.3-4 (2008): 129-134.
2. Neil, Mark AA, Martin J. Booth, and Tony Wilson. "New modal wave-front sensor: a theoretical analysis." JOSA A 17.6 (2000): 1098-1107.
3. Noll, Robert J. "Zernike polynomials and atmospheric turbulence." JOsA 66.3 (1976): 207-211.
4. Boruah, B. R. "Dynamic manipulation of a laser beam using a liquid crystal spatial light modulator." American Journal of Physics 77.4 (2009): 331-336.

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