Performance Measurement of an Adaptive Optics System for Free Space Optics Communication

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Abstract

The execution of free-space optics correspondence (FSOC) is incredibly corrupted by barometrical turbulence. Versatile optics (AO) is a successful strategy for lessening the impact. In this paper, a valuable measure of the proportion of the focal force of the picture of a guide source would be delivered by a flawless diffraction restricted telescope having a similar gap and throughput. The Strehl proportion (SR) which depends on the objective pictures is utilized to assess the execution quantitatively on the grounds that is identified with the impact of AO amendment straightforwardly. the impact of the spatial qualities of turbulence on the execution of AO in a FSOC framework is researched In view of the proportion of collector gap width to climatic intelligible length (D/r_0).

Key words: adaptive(AO) , Strehl ratio , turbulence strong ,FSOC

Introduction

Free space communication (FSOC) can be the successful alternative in wireless communications for radio frequency communications, characterized by high speed data transmission, high capacity, security and reliability in the transmission of information. However, the development of FSOC is limited by atmospheric turbulence. The amplitude fluctuation and wave-front distortion caused by atmospheric turbulence are the main factors that can severely degrade the coupling efficiency (CE) and increase the bit-error-rate (BER). To improve the performance of FSOC, an aperture averaging technique is typically used to attenuate the amplitude fluctuation with adaptive optics (AO) utilized to compensate for the wave-front phase distortion caused by atmospheric turbulence[1].

Versatile Optics (AO) is an innovation that permits ground-based optical and infrared telescopes to accomplish close diffraction-constrained picture quality, under specific conditions. On an extensive telescope, this gives an excess of a request of extent increment in determination and a few requests of greatness increment in sensitivity[2].

Versatile optics frameworks enhance picture quality by detecting and remedying the stage twisting presented by the climate. This is finished by an opto-mechanical framework that incorporates a wave front sensor, at least one deformable mirrors and a control framework.

The main objective of any adaptive optical system is to introduce a phase correction in the incoming wavefront that converts the aberrated wavefront into a plane wave. The adaptive optics technology was primarily used in astronomy in order to improve the image quality of the outer space, but nowadays we can find applications in many different fields such as free space communications, lidar systems, optical tomography, etc.[3].

The wavefront correction is usually performed by two separated set of mirrors: first is steering mirror, which performs the correction for the tip/tilt components, and a deformable mirror, which tries to compensate higher order modes.

Normal guide star versatile optics (NGAO(The most straightforward type of versatile optics utilizes light from a star to detect the barometrical stage contortion. This functions admirably as long as the star is adequately splendid. Something else, photon commotion confines the execution. To defeat the constrained sky scope of NGAO, laser-manage star versatile optics frameworks (LGAO) have been created. In these frameworks, a capable laser is utilized to make a simulated reference or guide in the atmosphere[4].

Multi-conjugate versatile optics (MCAO) frameworks give an answer for the issue of the little isoplanatic edge. This is finished by utilizing numerous laser reference points, and in excess of one deformable mirror. Multi-question (MOAO) a third sort of AO framework utilizes a different DM for every science target. These are put inside tests that can be moved to any situation in the field. Ground-layer (GLAO(a fourth kind of AO framework utilizes a solitary DM, conjugated to the ground layer, to give incomplete rectification (not diffraction constrained(of pictures over a wide field of view[5].

TheTheory

One of the main parameter to describe the wave front phase aberrations on the aperture plane of the receiver is the phase variance . When AO is applied, a correcting phase map is subtracted from the incoming phase wave front. The resulting residual variance of the corrected wave front is then expressed as[6, 7].

$$\sigma_{res}^2 = \frac{1}{\pi}\int(\varphi(\rho) - \varphi_c(\rho))^2\, d\rho$$

(1)

Two main techniques are used to characterize the wavefront error over a two-dimensional aperture: zonal and modal. The modal approach is based on the principle that the actuator is able to completely compensate j Zernike modes. where the phase variance was expressed in terms of the normalized turbulence strength and the number of corrected modes j. the correction phase map can be defined as

$$\varphi_{c,J}(\rho,\theta) = \sum_{j=1}^{J} \alpha_{c,j}\, Z_j$$

(2)

where are α(c,j) the Zernike coefficients of the correcting phase map Zj and is the j Zernike mode. The resulting residual phase error is then:

$$\sigma_j^2 = \sigma_\varphi^2 - \sum_{j=1}^{J} \left|\alpha_{c,j}\right|^2$$

(3)

Where σ_φ^2σ is the phase variance of the incoming signal. The residual errors , widely known as Zernike-Kolgomorov residual errors . The wave front correction is usually performed by two separated set of mirrors: first a steering mirror, which performs the correction for the tip/tilt components, and a deformable mirror, which try to compensate higher order modes. The reason for this is that the phase variance is not equally distributed over all Zernike modes. Actually, by removing the first two Zernike modes, the resulting phase variance is reduced by a factor of. Assuming that modal compensation can be applied to the tip/tilt components by using a fast steering mirror, the rest of the compensation is generally implemented by using zonal correction. In the zonal approach the aperture is composed by an array of independent sub apertures or zones. In each of these zones the wave front phase applied is estimated to minimize the resulting phase variance by performing a spatial average on each independent actuator [8]. The phase variance after zonal correction is expressed by:

$$\sigma_Z^2 = \frac{1}{\pi}\int(\varphi(\rho) - \varphi_Z(\rho))^2\, d\rho$$

(4)

where σ_Z^{2} is the phase map applied by the zonal corrector. In the section we describe the analytical expressions to evaluate the performance of these techniques(8)

An expression to estimate the standard deviation of the atmospheric tilt as a function of the telescope aperture is given by(7,8) :

$$\sigma_{tite} = \sqrt{0.184\left(\frac{D}{r_o}\right)^{5/3}\left(\frac{\lambda}{r_o}\right)^{2}}$$

(5)

$$\sigma_{DM}^2 = \sigma_3^2\sigma = 0.134\left(\frac{D}{r_o}\right)^{5/3}$$

(6)

$$S_{DM} = \frac{\lambda}{2\pi}.\,2.5.\,\sigma_{DM}$$

(7)

$$\mathrm{\sigma}_{\mathrm{res.m}}^2 = \mathrm{k}\left(\frac{\mathrm{r_s}}{\mathrm{r_o}}\right)^{5/3}$$

(8)

$$SR \approx exp\left[-k\left(\frac{r_s}{r_o}\right)^{5/3}\right]$$

(9)

$$SR \approx \exp(-\sigma^2)$$

(10)

$$\sigma_\theta^2 = \frac{1}{A}\int_A [\varphi(r) - \varphi(r + \theta h)]^2 d^2\, r$$

$$= \left(\frac{\theta}{\theta_o}\right)^{5/3}$$

(11)

$$\theta_o = \left[2.913\, K^2 sec^{\frac{8}{3}}\xi \int_0^{\infty} C_N^2\,(h) h^{5/3} dh\right]^{-3/5}$$

(12)

$$\frac{S(\theta)}{S(0)} = \frac{\exp(\sigma_\theta^2+\sigma_{\theta 0}^2)}{\exp(\sigma_{\theta 0}^2)} = exp(\sigma_\theta^2)$$

(13)

Simulation Results and Discussion

The research was adopted on an advanced computer program that allows the implementation of the FSO system field to describe, measure and perform different parameters under different levels of turbulences.

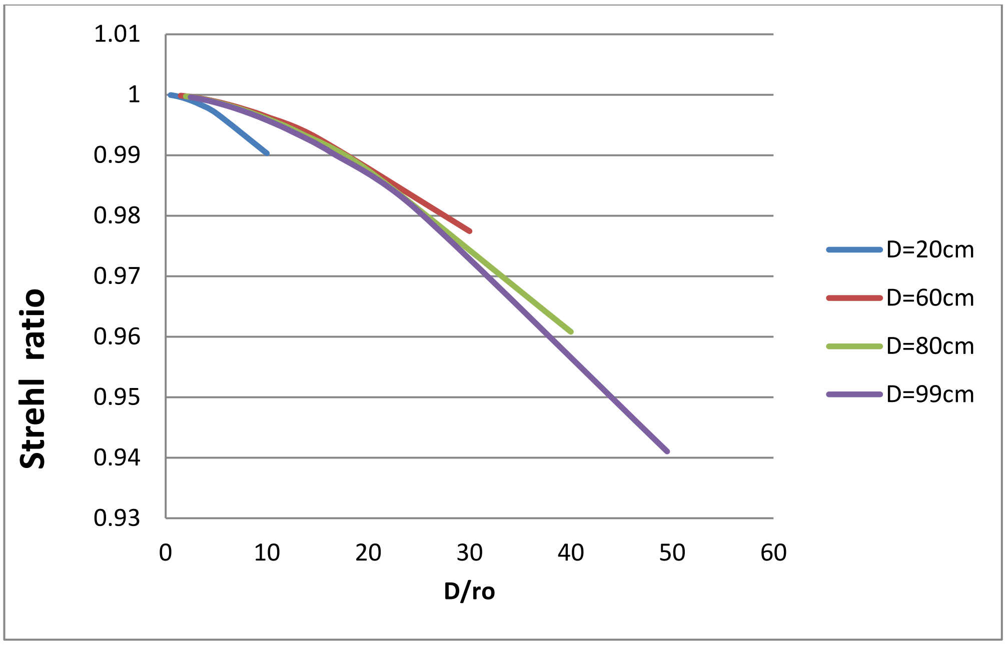
Figure (1)shows Strehl ratio achievable with D/r_0 consummate amendment of low order Zernike modes when D= (20,60, 80,99) cm respectively Also we need to include a 0.5 factor due to the fact that an angular movement of the mirror corresponds to twice the beam angular shift. Assuming that no amplification is used, the maximum angular depletion needed in our system is ±0.5mrad depletion needed in our system is ±0.5mrad.

Figure (2) Strehl ratio achievable with phase variance perfect correction of low order Zernike modes. From bottom to top, the curves correspond to correction of no modes, one mode (tilt), two modes (both tilt modes،(
three modes (tip-tilt and focus, four modes, etc.

Figure 3: shows the phase variance achieve as a function of D/r_0 after AO correction as measured for different J . the Strehl ratio is improved with increasing number of corrected Zernike modes. AO systems provided only low-order correction of the wave front

Figure 4: Number of modes that must be corrected to achieve of aStrehl ratio as a function of D/r_0 when aperture diameter(20,60,80,99).

Figure 5: Strehl ratio as a function of angle from the guide star, for conventional adaptive optics. The resulting Strehl ratio can be estimated using the Maréchal approximation



Figure(1): Strehl ratio achieve as a function of atmospheric turbulence .

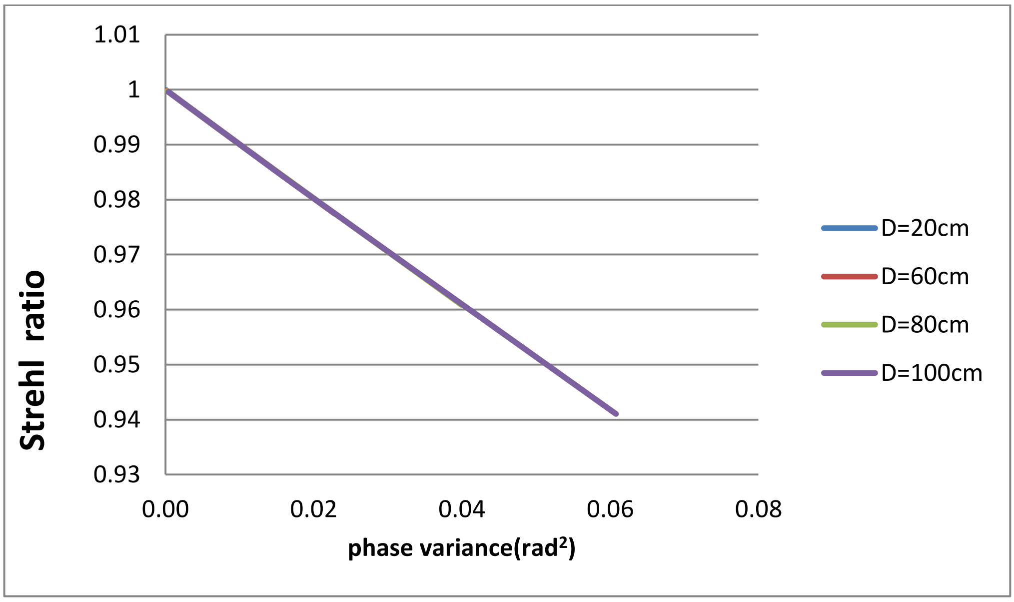


Figure 2: Strehl ratio achieve as a function of phase variance .

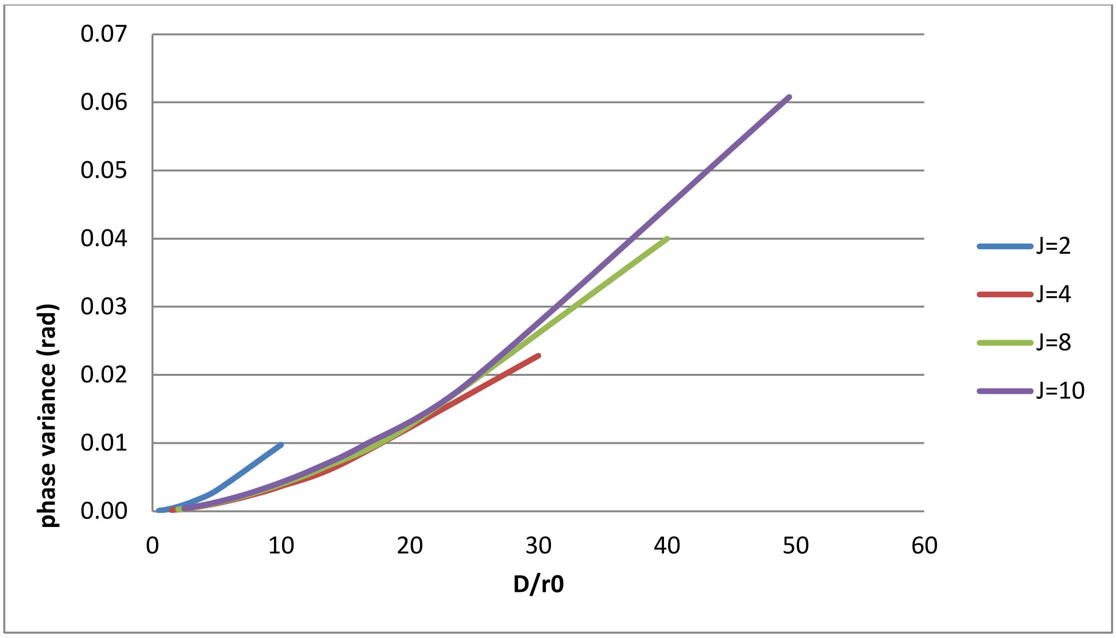


Fig. 3 Wave front phase variance for atmospheric turbulence when j modes are corrected for j=2,4.8,10.

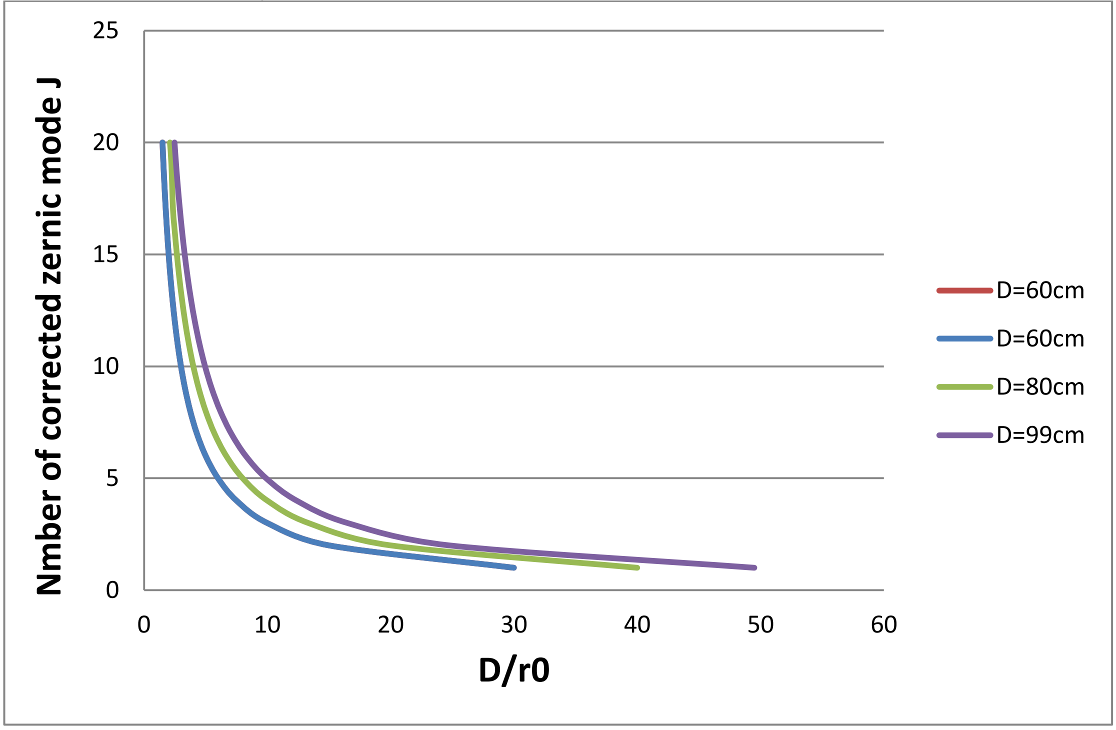


Figure 4: Number of modes that must be cured to achieve of a Strehl ratio of as a function of aperture diameter.

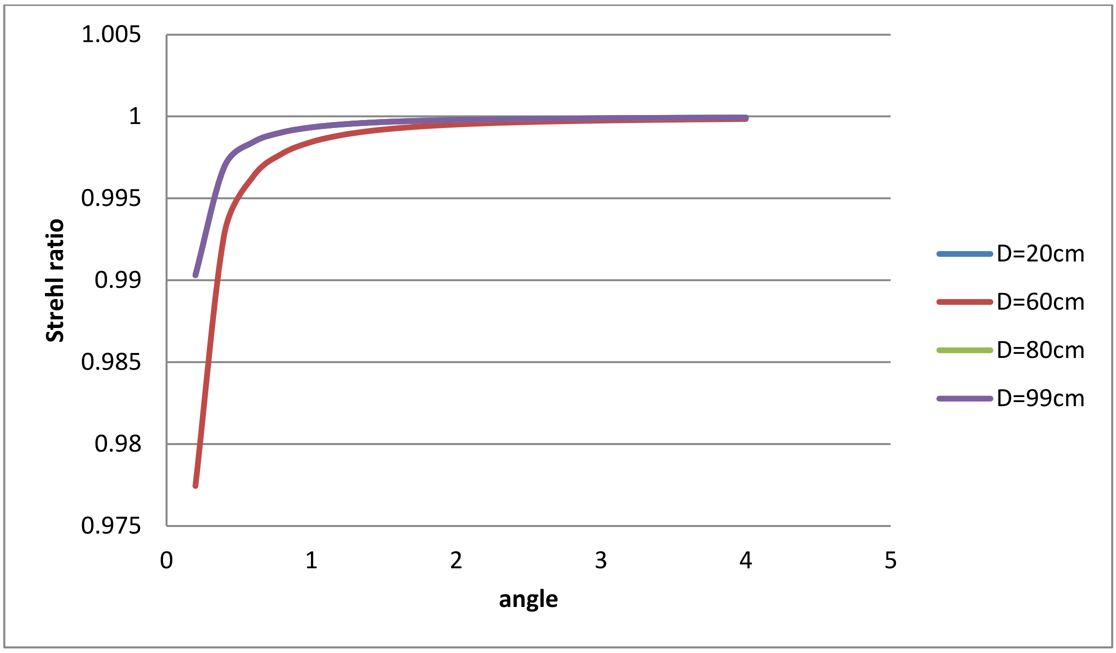


Figure5 : Strehl ratio as a function of the isoplanatic angle from the guide star, for traditional versatile optics for aperture diameter.

Conclusions

The influence of spatial characteristics of atmospheric turbulence for FSOC is investigated based on theoretical analysis of FSOC system and AO system. The quantitative relationship between AO parameters (number of corrected Zernike modes and bandwidth) and communication performance is derived for the first time. Then, simulations and programmed are carried out to analyze the influence of different spatial atmospheric conditions. The simulation and program results give lower bounds for the AO parameters, and demonstrates. The lower bounds for AO parameters can be used to guarantee the quality of communication. For common turbulence conditions (D/r_0), the number of corrected Zernike modes can be fixed; the bandwidth of the AO should be large to realize a good performance .The influence of the atmospheric spatial characteristics on FSOC performance is slightly stronger a higher bandwidth is necessary to guarantee the quality of communication .

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