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FIELD OF VIEW WIDENING IN NON-ASTRONOMICAL ADAPTIVE SYSTEMS.

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Fundamental limitation on field-of-view in a non-astronomical adaptive optical system due to its anisoplanatism is analyzed. Some possibilities of field-of view widening in adaptive optics are discussed. An estimation of possible isoplanatic patch of an adaptive system for retinoscopy is made using some heuristic approximation for irregular aberration structure function.

1 Introduction

Instrumental limitation in astronomical adaptive optics due to its anisoplanatism is well studied [1,2]. In most cases it restricts the angular size of the corrected zone up to a few arc seconds. The idea of enlarging the isoplanatic patch using a number of phase correctors [3] leads to complicated systems. If the distorting medium is stratified, the corrector location optimization and some modification of its control algorithm may give a good result [4]. These estimations are supposed to be useful especially for non-astronomical applications, when phase distortions are usually concentrated in one or a few layers. The main problem in such a case is that we usually have no reliable mathematical model of irregular aberrations, and the best thing one can do is to make up some heuristic model which does not contradict with experimental data.

2 The basic assumptions and block diagram of an adaptive system

The basic diagram of a system under discussion is shown in fig. 1.

The optical block contains a phase corrector, which image is located within the inhomogeneous layer. It is supposed that the rays passing through that virtual corrector are not restricted by the other optical elements. Thus, the virtual corrector is the input pupil of the adaptive system. Phase distortions for all the rays outgoing from each object point are summarized along the ray and with the phase shift, introduced by corrector. Then the result is averaged over the pupil area. Similar approach can be used in the case of two or more layers. To perform those calculations the structure function of phase distortion should be known. For atmospheric turbulence it is taken in a conventional form: $D(r)=6.88(r/r_o)$, where r_o

is the Fried's radius. For other applications we use "atmospheric-like" approximation $D(r)=(r/r_c)^{\gamma}$, where r_c is the correlation radius, and $1<\gamma<2$.

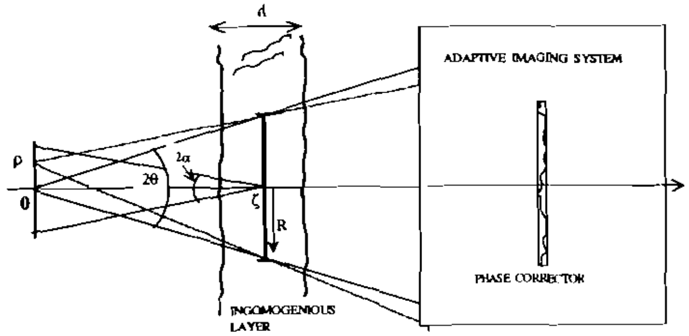


Figure 1.

3 Isoplanatic angle and residual mean square error estimation

3.1 Atmospheric layers

In fig. 2 the value of isoplanatic angle for a single turbulent layer is depicted versus the corrector image relative coordinate (L is the distance between the object and the input aperture). Relative coordinate of the layer center is taken 0.5. Relative thickness of the layer is the parameter. It can be seen from this figure that for thick layers (d>0.6L) optimization of the corrector position is not effective and its conventional location close to the input aperture does not decrease much the field-of-view. In the case of thin layers (d<0.2L), on the contrary, proper position of corrector is of great importance. The isoplanatic angle for such a thin layer is inverse proportional to its relative thickness. Residual error of adaptive compensation averaged over a certain area in the object plane for one, two and three thin layers is shown in fig. 3. Only for a single layer this error can be made zero by changing the corrector plane. For two or more thin layers and for a layer of a finite thickness only a minimum can be achieved. It is notable that the position of that minimum and its depth does not depend much on whether piston mode is removed or not. This result is in contrast with that known from astronomical application, when the corrector plane is located close to the input aperture.

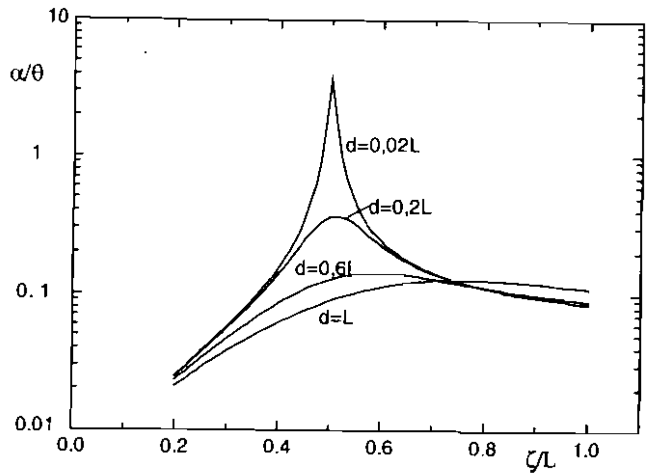


Figure 2. Isoplanatic angle dependence on the corrector location.

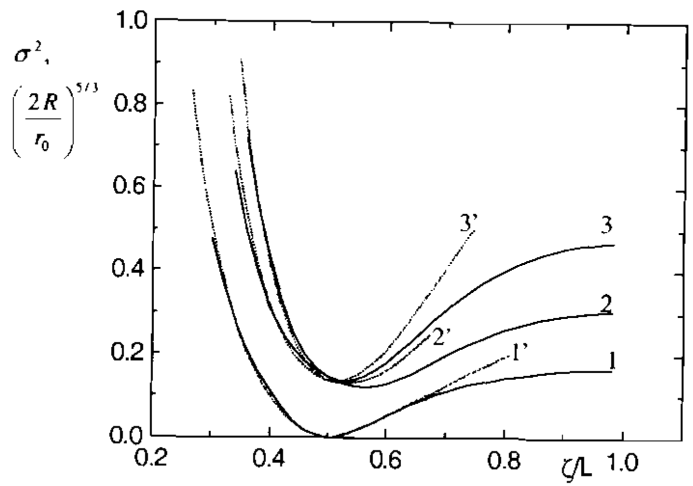
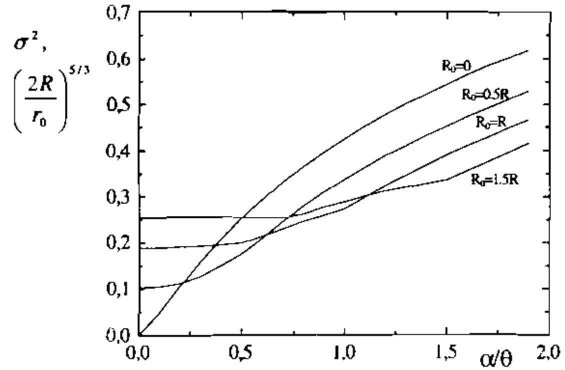
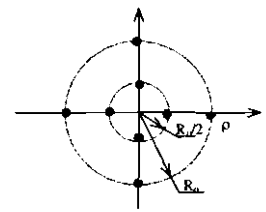


Figure 3. Mean square error dependence on the phase corrector location.
1 – one thin layer, $y=0.5L$; 2 - two layers, $y_1=0.4L$, $y_2=0.6L$, 3 – three layers, $y_1=0.4L$, $y_2=0.5L$, $y_3=0.6L$.
1, 2, 3 –piston removed. 1', 2', 3' – piston not removed.

3.2 *A multi-reference system*

Residual error of adaptive correction averaged over a certain area can be decreased if a multi-reference technique is used. In the algorithm proposed [4] the correcting phase shift is calculated as a weighted sum of the phases measured from different references. In fig. 4a the error distribution along the object is shown for a number of different angles between the references. The reference configuration (for 8 of them) is shown in fig. 4b. Zero distance between references means that a conventional single-reference system is analyzed. In a multi-reference system of that kind the residual error in the central region increases, while on the periphery it decreases. So a compromise for a given area can be found.





a) **b) Reference configuration.**

Figure 4. Mean square error in a multireference adaptive system. $R_0 = R\alpha/\theta$.

3.3 *Human Eye Aberrations*

Aberrations of human eye significantly reduce the quality of retinal image [5]. The contrast and resolution of retinal image can be improved by means of adaptive optics [6] within the isoplanatic angle of at least one degree. We try to estimate the isoplanatic zone of an adaptive system for retinal imaging and discuss some methods of its enlarging. This way of field-of-view widening is alternative to another one when only a small number of lower aberrations is compensated for by adaptive corrector and the others are reduced by a deconvolution algorithm [7].The main difficulty is that we do not have enough information to develop a reliable mathematical model for small-scale irregular aberrations, and only have to speculate about it. Nevertheless, some plausible estimation can be done. Using available data [5] about the mean square aberration coefficients dependence on its number, we tried to approximate it by $\varepsilon^2 = N^{-b}$, where N is the aberration number and b is an empirical value. We have obtained $b \approx 1.4 \sim 1.5$, which is significantly less than for the atmospheric turbulence. It means that if we use an "atmospheric-like" structure function γ should be less than the common value of 5/3. Estimation gave $\gamma \approx 1.33 \sim 1.56$, but that result is not very reliable because of insufficient statistics. The basic block diagram of an eye inspection system and its equivalent scheme are presented in fig. 5a,b. As the phase corrector and the distorting layer are placed now in parallel rays, the analysis of the isoplanatic angle leads to an universal dependence on a parameter η as it is shown in fig. 6. Here the mean square aberration suppression factor is depicted versus the normalized angle. Knowing the suppression factor required one can estimate the size of the isoplanatic patch.

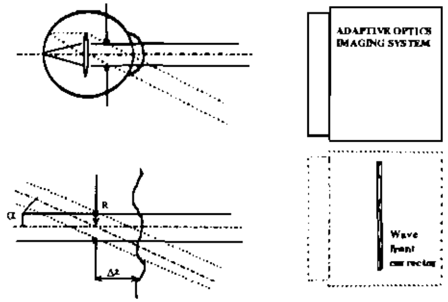


Figure 5. The basic block diagram of an eye inspection system.

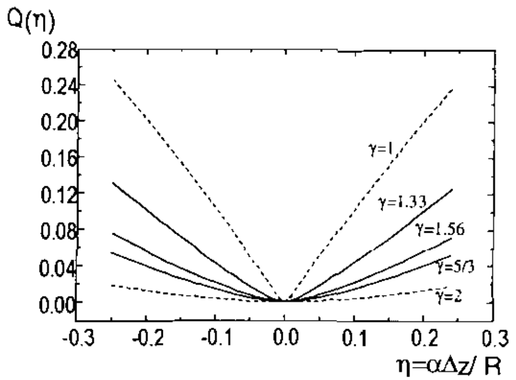


Figure 6. The mean square aberration suppression factor.

4 Discussion

Let us try to apply the results above to estimate the size of field-of-view of an adaptive device for retinoscopy. According to [5,6] mean square aberration cased by irregular distortions (N>4) is about $\varepsilon^2 = 2.5$. The desired level of aberrations over the field-of-view for diffraction limited image is $\varepsilon^2 = 0.15$. So the suppression factor should be Q=0.06. This is an "optimistic" estimation. In the other case it may be supposed that all aberrations including the large scale ones are to be corrected. In that case we obtain a "pessimistic" estimation of the suppression factor of Q=0.005. To make use of these estimations we approximated the upper curve in fig.6 by an empiric formula $Q=0.78\eta^{1.2}$. That leads to an estimation of the isoplanatic patch angular size: $\alpha = (R/\Delta z)\,(Q/0.78)^{0.85}$, where R is the eye pupil radius (in our case it was 7.3/2 =3.65 mm) and Δz is the distance between the pupil and the distorting layer. We take here the worst possible situation when the most intensive distortions lay near the outer surface of the eye. In this case Δz is also about 3.5 mm. These values leads to an "optimistic" corrected field-of-view of 6 angular degrees, and "pessimistic" – of 0.85 degree. We believe that these estimations are in good accordance with experimental results [6].

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