

Deformable mirrors for low-order correction

Gleb Vdovin, Oleg Soloviev, Mikhail Loktev

Flexible Optical BV, Polakweg 10-11, 2288 GG, Rijswijk, The Netherlands

OKO@okotech.com

Introduction

In most applications, the adaptive optics is applied to improve the performance of otherwise impaired system. Ideally, it should be invisible, cheap, and cause no trouble. But in real life, introduction of adaptive optics usually means a considerable increase in the system complexity, bringing advantages and problems in a single package.

The mutual goal of the developers and users of an AO system is the optimization of the performance, keeping the complexity low. Less complexity means higher reliability, simpler, cheaper and easier to set up and more robust system. The goal of high performance and low complexity in one package can be reached by tuning the parameters of the adaptive optical system to the expected aberrations

Wavefront correction

Adaptive optics can be used to optimize almost any measurable parameter of an optical system, including the output power of a laser, beam quality, Strehl number, image sharpness, pulse shape, pulse duration, beam focus, etc. The improvements are generally achieved by changing the wavefront of the light wave.

The control loop of the AO system minimizes the error by a using the best possible combination of the corrector's modes. If the correction is not satisfactory, the number of modes is increased. This approach leads to a commonly accepted wisdom that a good adaptive optical system should have many control channels and - as a consequence - be expensive. However, in many cases, a very good result can be achieved with only a small number of correction channels, by statistically matching the influence functions of the corrector to the most expected aberrations.

Statistics of aberrations

The best possible fit, reaching maximum precision with the minimum number of modes is given by the Karhunen-Loeve (KL) functions, with eigenvalues corresponding to the statistical weights of the corresponding terms. Each optical system has its own aberration statistics, requiring building a specific set of KL functions, which is usually impossible, as the statistics is unknown. A well-studied case of the atmospheric turbulence gives some useful clues. It was found that the Karhunen-Loeve functions of the aberration statistics of the atmospheric turbulence are very close to Zernike polynomials. On the other hand, the classical theory of optical system also uses Zernike polynomials to describe the most important aberrations of optical systems: tip, tilt, defocus, astigmatism, coma, trifol, and spherical aberration. Thus, we can assume that in most cases, the aberrations described by the first Zernike terms will be the most prominent in a general optical system, regardless of their nature. This is a rather strong sentence and there is a great chance that it is not always correct, but we just do not have any better.

Quasi-optimal correctors

The tip-tilt (misalignment) and third-order Zernike terms are the most statistically significant aberrations in the majority of optical systems. Correction of these aberrations dynamically is the primary goal of adaptive optics. Fast correctors of tip-tilt (scanners) are available from a number of companies. They close the gap between the "traditional" and the

"adaptive" optics, in a sense that they provide fast dynamic correction, but are not really adaptive. One has to expect the tip-tilt correction to be a simple task; however the dynamic correctors are quite expensive, especially if they work in a calibrated feed-forward mode.

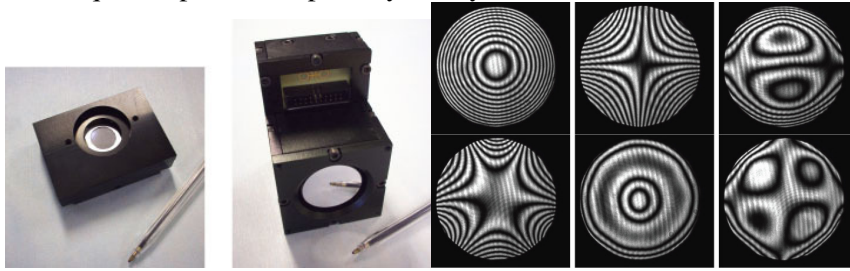


Fig. 1: 17-ch membrane deformable mirror with integrated tip-tilt capability and the 19-ch piezoelectric mirror optimized for correction of low-order Zernike terms (left). Live interferograms of low-order Zernike terms, obtained with the 19-ch piezoelectric mirror (right).

And there is a problem of two separate correctors: usually a scanner stage is used for tip and tilt, and a separate deformable mirror is used to correct higher order aberrations. Since both correctors should be positioned in the system pupil, an additional imaging telescope is applied to achieve the pupil conjugation, resulting in a more complex, less compact system with higher losses and scattering. In some cases it is possible to use the deformable mirror in a scanner mode - most deformable mirrors can correct small amounts of tip and tilt, however it restricts the correction range for other aberrations, and the quality of correction is usually unsatisfactory as tip and tilt do not belong to the eigenfunctions of a typical deformable mirror. To solve this problem, we, in OKO Tech, have developed a special corrector, featuring a membrane deformable mirror with 17 actuators [2] for correction of all 3-rd order aberrations, mounted on a fast tip-tilt stage. The mirror is shown in Fig. 1.

Appropriately coated micromachined membrane mirrors can work with continuous laser power of up to hundreds of W, however they are not suitable for laser applications in the kW range. For these applications, we have developed a piezoelectric deformable mirror with a special actuator configuration providing very good correction of low-order Zernike terms in the aperture of 20 mm (30 mm mirror), and 35 mm (50 mm mirror). Response optimization is achieved by positioning most of the actuators outside the clear aperture of the mirror [3], providing the best possible match between the mechanical response of the mirror, and the statistically most expected aberrations, as seen in Fig. 1. These mirrors can be specially coated for high-power applications with continuous power densities of up to several kW/cm².

Conclusions

In many scenarios the goal of simple, efficient, and inexpensive adaptive optics can be achieved with a minimum effort by using correctors matched to the statistics of the expected aberrations. Such correctors, combining deformable mirror and tip-tilt stage in a single device, offer good performance for a fraction of the price that should be paid for a more complicated multichannel system with separate subsystems for tip-tilt and adaptive optics.

References

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