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# Characterization of close-loop performance of double drive modes unimorph deformable mirror

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## Abstract:

Unimorph deformable mirrors are attractive in adaptive optics system due to their advantages of simplicity, compact, low cost and large stroke. In this paper, a double drive modes unimorph deformable mirror is discussed, which comprises a 100  $\mu\text{m}$  thick PZT layer and a 200  $\mu\text{m}$  thick silicon layer. This deformable mirror (DM) can achieve two different directions deformation of concave and convex driven by only positive voltage. The dual direction maximum defocus deformations are -14.3  $\mu\text{m}$  and 14.9  $\mu\text{m}$ . The close-loop performance of this DM is also tested in an experimental adaptive optics system based on Hartman-Shack wavefront sensor. In experiments, the DM is controlled by the steepest descent algorithm (SD) to corrected the aberrations in a close-loop manner. The ability of this DM of correction for the system aberration and reconstruction for the low order Zernike mode aberration is tested. The root mean square (rms) value of the system aberration after close-loop correction is about 28 nm. The reconstruction results for most low order Zernike mode aberrations have a relative error less than 10%.

**Key words:** adaptive optics system, unimorph deformable mirror, double drive mode, close-loop performance.

## 1. Introduction

Adaptive optics was originally developed to correct the aberrations induced by atmospheric turbulence for ground-based astronomical telescope<sup>1</sup>, next it was successfully used to correct optical aberrations in many different fields, such as vision science<sup>2</sup>, microscopy<sup>3</sup> and high power lasers<sup>4</sup>. In a conventional adaptive optics system, a wavefront sensor such as Hartman-Shack wavefront sensor is usually employed to measure the optical aberrations and a deformable mirror (DM) is used to correct the aberrations and a control system is used to link the wavefront sensor and the deformable mirror.

In the AO system, a deformable mirror (DM) is a critical component working as a wavefront corrector. Various kinds of DMs have been developed and used in different applications, such as the piezoelectric stack deformable<sup>5</sup>, electrostatic MEMS deformable mirror<sup>6</sup>, and so on. Among various DMs, unimorph deformable mirrors are attractive in adaptive optics system due to their advantages of simplicity, compact, low cost and large stroke for correcting low-order optical aberrations (such as defocus, astigmatism, coma and spherical aberration)<sup>7</sup>. For most aberrations are low order aberrations in general applications, and the optical performance can be improved significantly after the low order Zernike aberrations corrected, unimorph DM have been frequently used in various applications.

In this paper, a new kind of unimorph deformable mirror called double drive modes unimorph deformable mirror<sup>8</sup> is investigated. This kind of unimorph DM has the ability to achieve symmetric convex and concave deformation with only positive drive voltage. The close-loop performance of this DM was characterized. The ability of this DM of correction for the system aberration and reconstruction for the low order Zernike mode aberration is analyzed in simulations and experiments.

## 2. Structure of Double Drive Modes Unimorph Deformable Mirror

The layout of the double drive modes unimorph DM is illustrated in Fig. 1. The DM comprises of a 100  $\mu\text{m}$  thick PZT layer and a 200  $\mu\text{m}$  thick silicon layer. These two layers are glued together, with edge supported rigidly. The metallization on backside is patterned to produce 38 electrodes (one outer ring actuator, and 37 inner hexagonal actuators which are arranged hexagonally). The uniform metallization between the silicon layer and the PZT layer is used as ground electrode. The overall size of the DM is 40 mm in diameter, with only the central area with diameter of 15 mm used for optical correction.

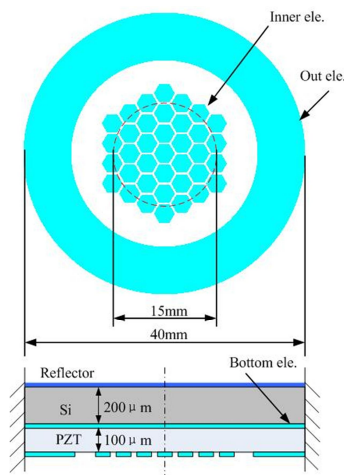


Fig. 1. Layout of unimorph DM: plan view of electrodes (top) and cross-sectional view of the DM (bottom).

Due to the restriction of the fixed supported boundary, when the DM is driven by positive voltage, the outer ring actuator generates overall concave defocus; while the single inner actuator generates local convex deflection. These two opposite deformations in the active aperture are counteracted when appropriate voltages are applied on both the ring actuator and the inner actuators, resulting in a flat surface. In order to correct an aberration that has both positive and negative curvature, the ring electrode is normally biased at a constant voltage to produce a pre-deformed concave shape with an approximate deflection to the half of the maximum convex defocus generated by those 37 inner actuators. The inner electrode voltages are varied to correct wavefront aberrations. The dual direction maximum defocus deformations are  $-14.3 \mu\text{m}$  and  $14.9 \mu\text{m}$ .

## 3. Simulation

To test the close-loop performance of this DM, numerical simulations of correction for the system aberration and reconstruction for the low order Zernike mode aberration were carried out. The imperfect initial surface shape of the deformable mirror is supposed as the system aberration and the Zernike expansion coefficients of the aberrations is

shown in Fig. 2. In simulations, the steep descent (SD) algorithm<sup>9</sup> is used to control the DM, and the root mean square (rms) values of the residual wavefront aberration was selected to be the evaluation function. The rms value of the initial aberration is about 230nm. The simulation results for correction the system aberration are shown in Fig. 3. It can be found that most of the system aberration is corrected after about thirty iterations and the residual wavefront rms value is about 30nm. The simulation results of correction low order Zernike mode aberration are shown in Fig. 4. As shown in Fig.4, the low order Zernike aberration can be corrected well using this DM and the 10<sup>th</sup> Zernike aberration can be corrected with a relative error less than 20%.

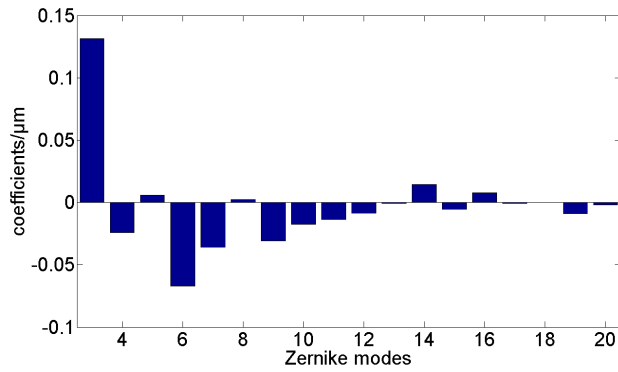


Fig. 2 The Zernike expansion coefficients of the system aberration

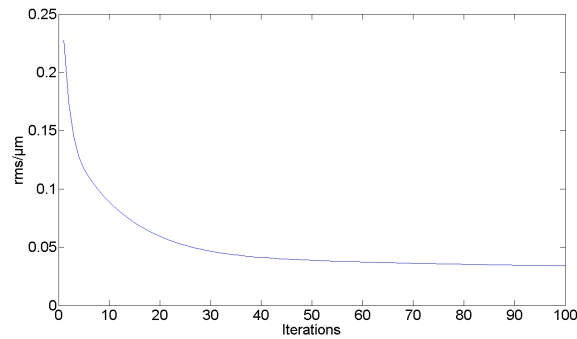


Fig. 3. The simulation results for correction the system aberration.

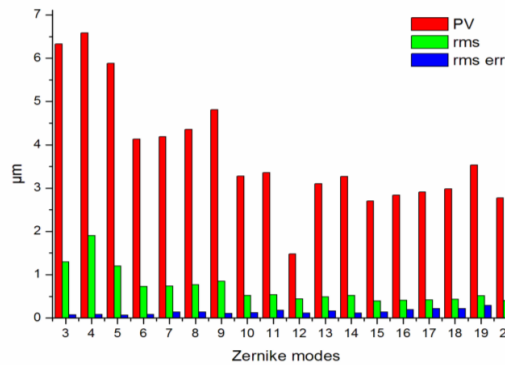


Fig. 4 The correction ability for low order Zernike aberrations.

#### 4. Experimental setup

An experimental adaptive optics system based on the Hartman-Shack wavefront sensor was established to verify the close-loop performance of the double drive modes unimorph DM. The schematic of the experimental setup is illustrated in Fig. 5. A polarized 633nm helium-neon laser is selected as the light source. After being expanded and collimated, the light beam passes through a beam splitter (BS) and reaches the DM which is driven by 37-channel high-voltage amplifier (HVA). Then the reflected beam from the DM passes through an aperture (AP) corresponding to the effective aperture of the DM, and a down-collimator. Finally the beam reaches the Hartman-Shack wavefront sensor, which measures the beam's current wavefront in real time. After the wavefront has been measured, the voltages of the DM's electrodes can be calculated based on the influence function matrix, which describes the relationship between the applied control voltages and the responding deformation. After several iterations of close-loop correction, most of the aberrations can be corrected.

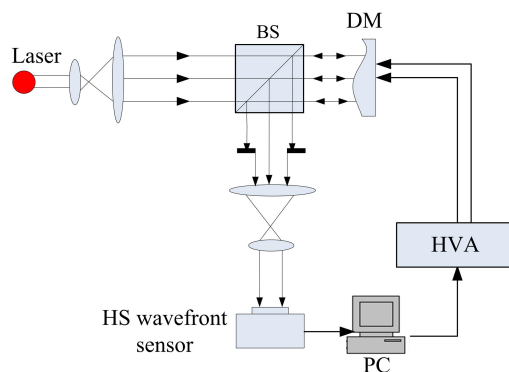


Fig. 5. Schematic illustration of the experimental setup for close-loop aberration correction.

#### 2. Results and Discussion

The experiments of correction system aberration and reproduction low order Zernike aberration are all carried out to characterize the close-loop performance of this unimorph DM. The correction results of system aberration is shown in Fig. 6. From the curve of the residual aberration rms in the close-loop correction, it can be found that the initial aberration has a rms value about 175nm, and after correction the residual wavefront rms value is about 28nm. It can also be found the rms value have almost reached the final value after about 20 iterations, so the quasi-static aberrations can be corrected well and fast using the double drive modes unimorph DM.

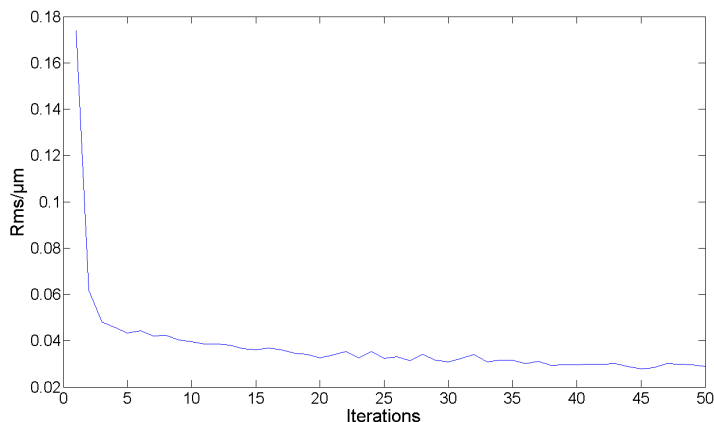


Fig. 6 The experimental results for correction system aberration.

The reproduction results of the 20<sup>th</sup> Zernike modes are shown in Fig. 7. From the measured wavefront, it can be found the reproduced wavefront is almost the same as the standard Zernike mode wavefront. From the compare between the reproduced wavefront rms and the error, it can be found that this DM has good correction ability for the low ord Zernike aberration. Simulated and experimental normalized wavefront error of the reproduced 20<sup>th</sup> Zernike mode aberration is shown in Fig. 8. The results of simulation and experiments are quite consistent with an acceptable error. It can be found that reproduction results of most of the 10<sup>th</sup> Zernike aberrations have a relative error less than 10%.

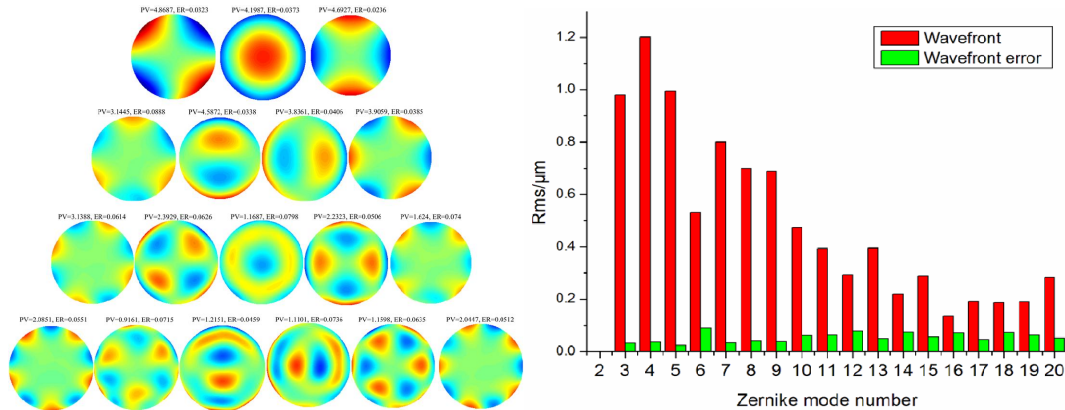


Fig. 7 Reproduction results for the 20<sup>th</sup> Zernike mode. (left) measured wavefront (right) reproduced wavefront rms and rms error.

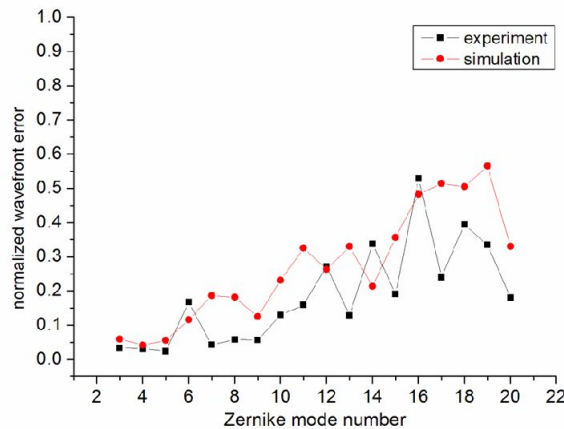


Fig. 8 Simulated and experimental normalized wavefront error of the reproduced 20<sup>th</sup> Zernike mode aberration.

## 5. Conclusion

This paper describes the close-loop performance of the double drive modes unimorph DM, which has the ability to achieve symmetric convex and concave deformation with only positive drive voltage. Numerical simulations of correction for the system aberration and reconstruction for the low order Zernike mode aberration were carried out. An experimental adaptive optics system based on Hartman- Shack wavefront sensor was established to verify the close-loop performance of this DM. The results of both simulations and experiments demonstrate that this DM has good correction ability for the low order aberrations.

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