Evolving Research on a Non-contact Adaptive Optic Actuation Method for Wavefront Correction

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Abstract

This paper presents the research on a high precision contactless actuation mechanism for an adaptive optics system. The mechanism is based on thermal expansion. The paper presents the research on linearity, the effect of superposition and the resolution of this actuation concept. Results of experiments carried out have nanometer resolution on shape and sub Kelvin resolution on temperature.

1 Introduction

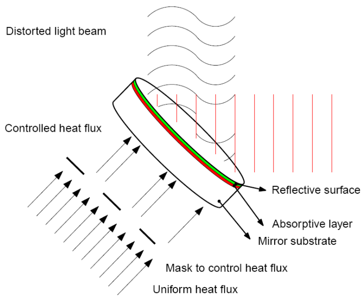
Adaptive optic systems are used in ground-based telescope systems to correct atmospheric wavefront distortions. Current adaptive optical systems are also used in microscopes, high power lasers and tomography to correct for tissue density and lens heating effects. Current optical system drawbacks are quasi-static phenomena like creep, hysteresis, heat and dynamic vibrations to the optical components.

The traditional approach of mounting many different actuators between the Deformable Mirror (DM) and a reference frame has some drawbacks. The manufacturing process is complex and mechanical coupling between the frame and the DM can cause dynamic and static surface inaccuracy.

For this reason a contactless thermal actuation principle as proposed in [1] is preferred. This paper presents the ongoing research concerning the development of such an actuation principle as we presented in [2]. A breadboard setup has been built up to verify the linearity, the effect of superposition and resolution of this actuation concept.

2 Actuation principle

The actuation principle is shown in Figure 1, left and consists of a mirror and a spatially controllable radiant heat source. The DM is relatively thick, transparent for the radiant heat source and has a bi-layered coating, which consists of an absorptive coating on the mirror substrate and a reflective coating on top of it. The absorptive layer will absorb the radiated heat, causing an increase in temperature and a deformation at the mirror surface. The shape and speed of deformation can be controlled by adjusting the adjustable source or mask, which selectively exposes the mirror with respect to intensity and spatial distribution.



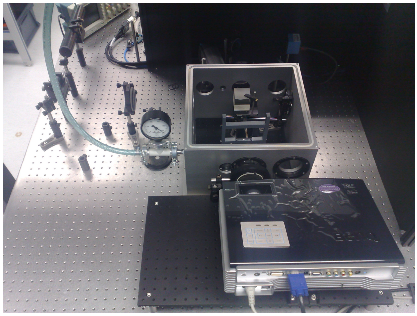


Figure 1, left: the actuation principle. A distorted light beam is corrected after reflecting off a deformable mirror. The correction is done by selectively heating and so deforming the mirror surface. Figure 1, right: a picture of the experimental setup. Left a He-Ne laser and optics to expand the beam for the Michelson interferometer. In the vacuum chamber the reference mirror, and a normal beam splitter are placed; in the back of the setup (hardly visible) a camera to capture the interference pattern, and a thermal camera and in front a video projector as controllable heat source.

3 Experimental setup

The experimental setup is shown in Figure 1, right and consists of a breadboard setup that can measure both temperature and deformation and has a controllable heat source. The deformation is measured with a Michelson interferometer, with a beam diameter of 50 mm. The interference pattern is captured with a 786x1024 pixel CCD camera, which sample at 30 Hz and is analyzed with a carrier fringe method afterwards [3]. For each measured topology 100 interferograms are captured, analyzed and averaged, with 5nm RMS.

The temperature is measured with a thermal imaging camera FLIR A316, with 240x320 pixels, 60 Hz sampling, and 45 mK NETD. Only a part of the image is used, because there is a distance of 300 mm between the object and the camera. Additionally, because the beam splitter is obstructing the camera view, the DM is shown on an angle. The spatially controlled radiant heat source is a video projector with 5000 Ansi Lumens optical power, that uses DLP technique. The exposed area is about. 60x50mm^2. The beam splitter, the reference mirror and the DM are placed in a vacuum chamber, which has a pressure of 10 mBar, to reduce fluctuations in the refractive index, and to restrict the heat exchange to radiation.

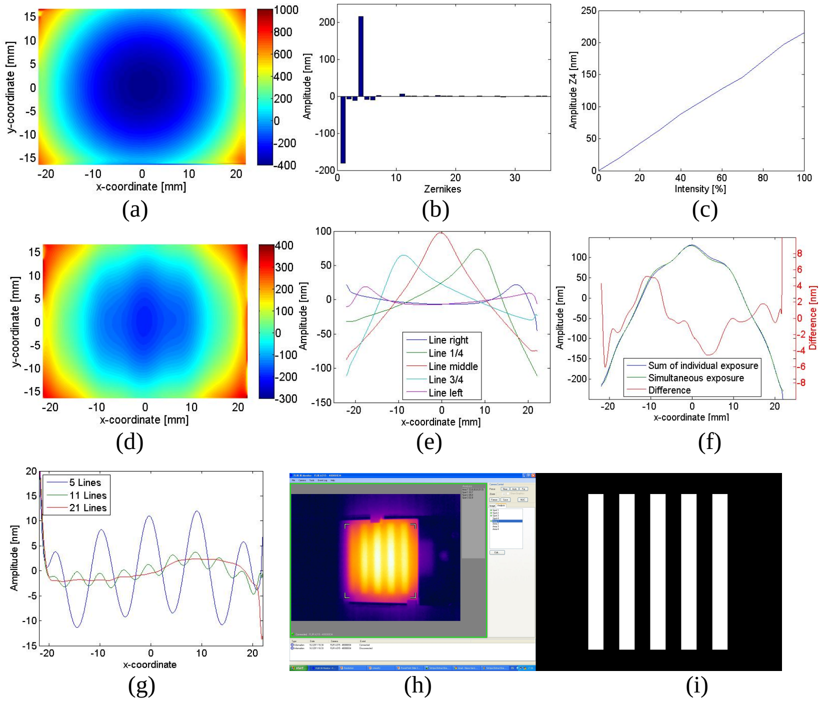


Figure 2: Results of the experiments. Figure 2(a-c) shows that the deformation is proportional to the light intensity, when exposing the substrate uniformly; 2(a) shows the spherical deformation, caused by the uniform exposure; 2(b) shows the contribution of the spherical deformation in nanometre; and 2(c) the relation between the exposure intensity and the deformation. Figure 2(d-f) shows superposition; 2(d) shows the topology after exposure of the five lines simultaneously; 2(e) shows the mean deformation over the width of the mirror surface, for exposing the individual lines separately; 2(f) shows the sum of the five lines of 2(e) and the simultaneous exposure. Figure 2(g) shows the results of determining the resolution; it should be mentioned that a second order polynomial is subtracted from the measured topology. Figure 2(h) shows the thermal distribution of a sample exposed with the pattern shown in Figure 2(i). The thermal image is

taken after 2 minutes of exposure. It shows that the mirror can heat up to 33.7 degrees and 0.8 degrees difference between the lines.

The deformable mirror is a BK7 50x50x4 mm^3 substrate, coated with a broadband optical absorptive coating, absorbing 96% of the light, and a reflective coating on top for the interferometer visibility. For the thermal image a BK7 substrate with only the absorptive coating is used.

4 Experiments and Results

The exposure patterns on the mirror have different purposes. First, the mirror is uniformly exposed at intensities from zero to the maximal intensity, in steps of 10%. This verifies the linearity of the concept. Second, 5 bright lines are exposed and measured, first individually and than simultaneously. This verifies the superposition of the concept, since the calculated sum equals measured sum. Third, the mirror is exposed to a spatial block wave, with decreasing period, until the deformation disappears in the noise. This experiment determines the resolution that can be obtained using this experimental setup.

The results of these experiments are shown in figure 2. Figure 2(a-c) shows that the concept is linear when the mirror is exposed to a uniform heat flux. Figure 2(d-f) shows that superposition can be applied and Figure 2(g) shows the resolution that can be measured in this setup and is above 0.24 [mm^{-1}].

5 Conclusions

This research shows a Deformable Mirror that can correct in the whole aperture with nanometer amplitude and a spatial resolution above 0.24 [mm^{-1}]. Experiments show linearity and that superposition can be applied.

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References:

[1] R. Lawrence et all; Active correction of thermal lensing through external radiative thermal actuation; Optics Letters, 2004

[2] R. Saathof et all; Non-contact adaptive optic actuator system for wavefront distortion correction; ASPE Atlanta 2010

[3] Jansen MJ. Development of a wafer geometry measuring system: A double sided stitching interferometer [PhD Dissertation]. Technische Universiteit Eindhoven; 2006.