ACTIVE OPTICAL SYSTEMS

AN053

On the Curvature of DM Plate-Type Influence Functions

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1 Introduction

Several researchers have inquired on the potential applicability of plate-type DMs as an actuator for curvature-based wavefront sensor feedback control. A curvature WFS typically uses the intensity difference between two planes on equidistant from either side of a nominal focus to estimate the curvature of the wavefront. If the DM has actuator influence functions that induce a localized curvature on the DM surface, the curvature wavefront sensor output (the intensity difference) can be directly applied (or applied through integrator control) to the DM to achieve high speed compensation. The two DM architectures that are typically used for this type of adaptive optics (AO) system are the bimorph or membrane DM, but plate-type DMs are a potential candidate as well. This application note investigates this potential.

2 Approach

We have routinely found that plate-theory does an excellent job of predicting the influence function (IF) shape achieved by a plate-type deformable mirror (Timoshenko, Theory of Plates and Shells). We use plate-theory to generate influence functions in the AOS AO Simulator software. The central IFs are very similar to the Greens function shape derived in earlier work, but the edges are very different due to the more accurate modeling of the boundary conditions.

To evaluate the potential for a plate-type DM in a curvature AO system, we considered the actuator pattern shown in Figure 1. We used plate-theory to generate the IF shape and then analyze the curvature of this shape and examine how a curvature WFS might respond to this IF shape.

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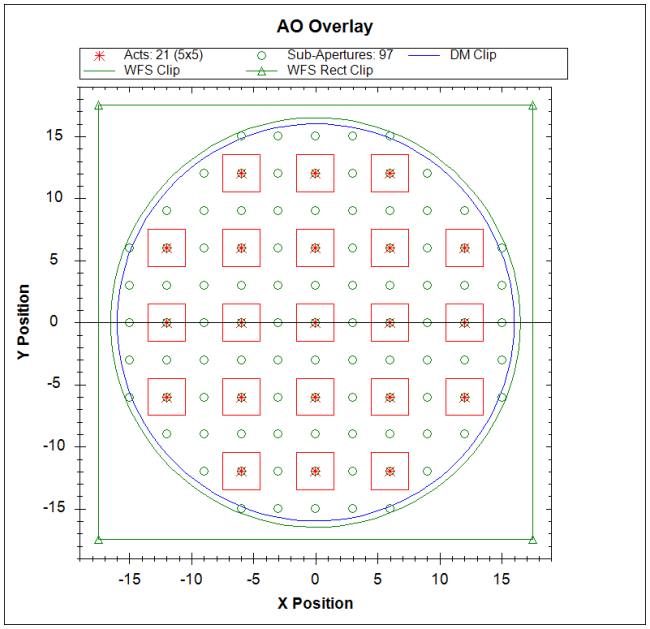

Figure 1: DM Actuator Pattern

3 Results & Analysis

3.1 Influence Functions

Figure 2 shows the influence functions generated via plate theory. Each plot is on a floating colorbar. The top left plot is simply a display of the colorbar for clarity. The influence functions are arranged in a pattern identical to the actuator pattern of the DM. For many of these plots, we used an hue-satured value (HSV) colorbar and a grayscale colorbar to facilitate understanding and plotting of this information.

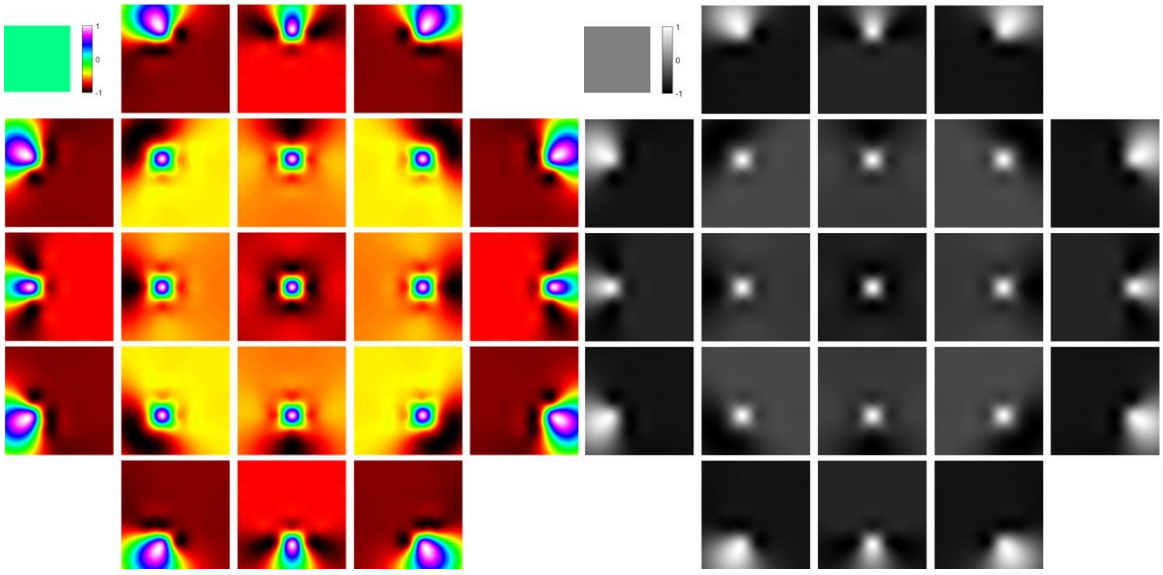

Figure 2: Plate-Type Influence Functions on a HSV (left) and Grayscale (right) Colorbar

Figure 3 shows the high resolution curvature of each of the DM influence functions. Again, the figure in the top left is a representation of the colorbar for clarity. It is clear from these plots that the curvature at the center of each actuator influence function is uniquely low and the surrounding peaks are points between the firing actuator and its neighbor.

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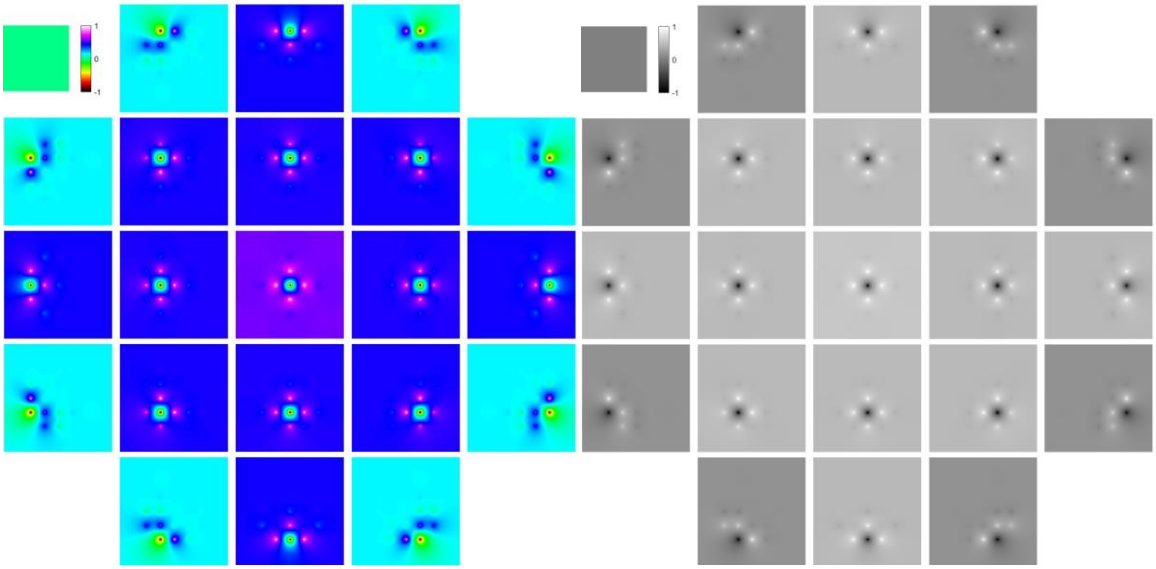

Figure 3: Second Derivative (Curvature) of the Influence Functions in HSV (left) and Grayscale(right) Colorbars

We processed this high resolution actuator curvature signal into a lower resolution by averaging the curvature centered on each actuator over an area equal in square size to the actuator spacing. Figure 4 shows the low-resolution curvature sensor results. The curvature sensor was predicting a localized negative curvature in the sub-aperture associated with each of the actuators and positive curvature or zero curvature elsewhere. This result indicates that the curvature sensor should be able to be used with the plate-type DM as part of a compensation scheme.

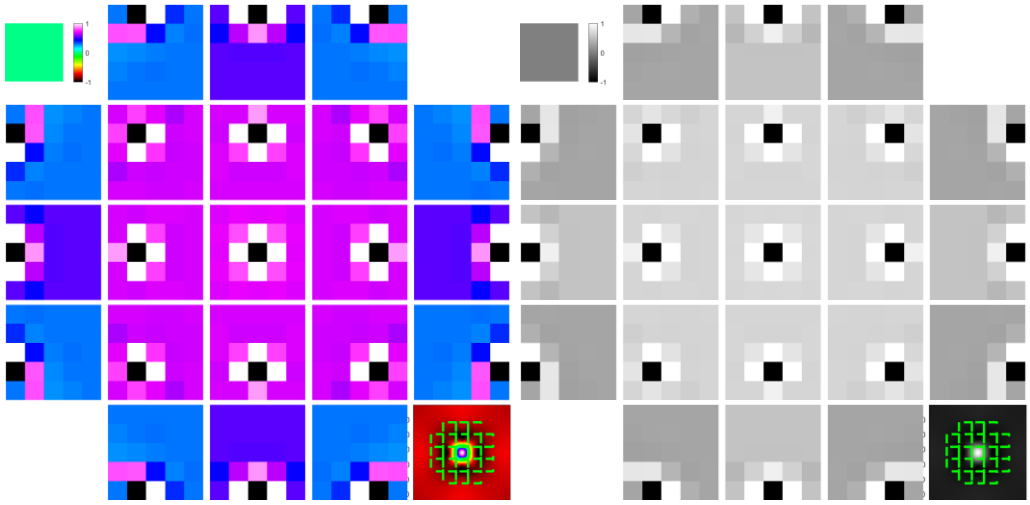

Figure 4: Low-Resolution Influence Function Measurements of the Curvature Sensor in HSV (left) and Grayscale (right) Colorbars

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3.2 Waffle Mode

To test the efficacy of the curvature sensor approach, we measured the DM in a waffle pattern. Figure 5 shows the DM surface in a waffle pattern in which the actuators area firing in a checkerboard pattern with an overlay of the actuator-centered curvature-sensor sub-apertures.

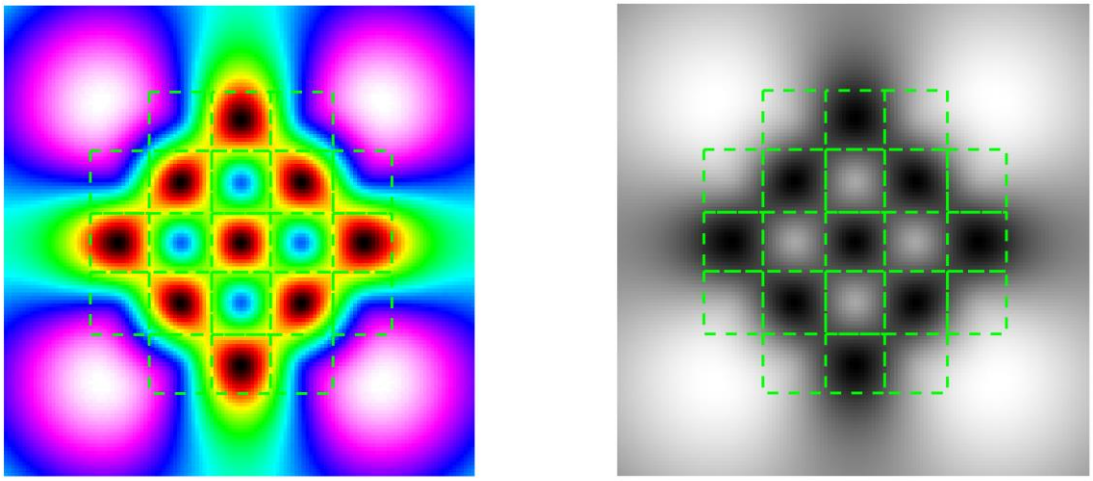

Figure 5: Waffle Surface Pattern with Sub-Aperture Overlay in HSV (left) and Grayscale (right) Colorbars

Figure 6 shows the waffle surface data processed into a sub-aperture resolution curvature signal. The corners were areas were no actuators were present, so the curvature there is expected to be zero. The other edge actuators were showing less curvature than the center because the boundary conditions of these actuators was not constrained on the outer edges. Other than the understood minor edge variations, the expected checkerboard pattern was achieved. The edge performance variations should be able to be compensated with a slightly different spatially varying gain.

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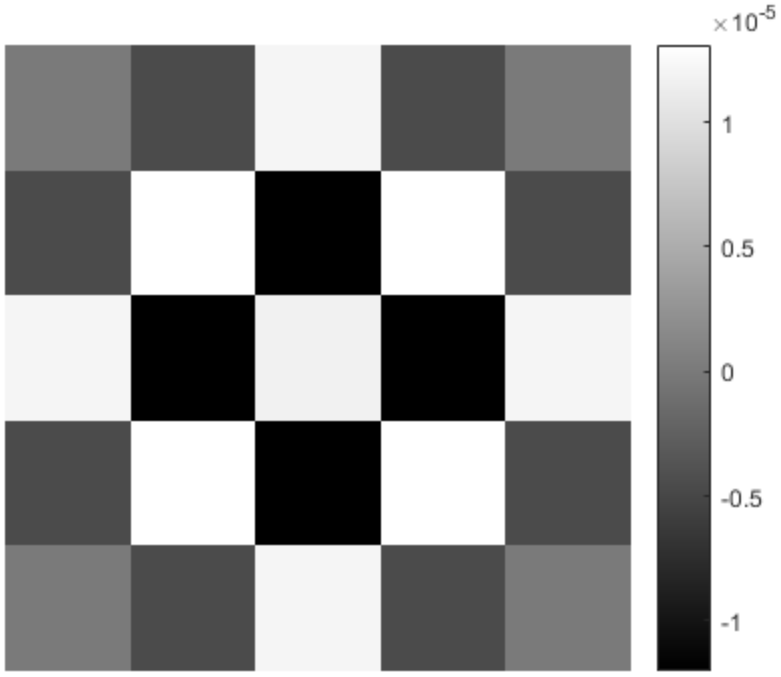

Figure 6: Sub-Aperture Resolution Curvature Signal of the Waffle Pattern

3.3 Poke Matrix Analysis

As a final step, we combined all the low-resolution curvature measurements into a single poke matrix and analyzed it. The condition number of the poke matrix was only 35 (where 1 is perfectly orthogonal rows and columns and infinity is singular). We used single value decomposition (SVD) to invert the matrix with no modes removed. Figure 7 shows the poke matrix, SVD gains, and the inverted poke matrix used to make a control matrix. The RMS difference between the normalized poke matrix and the identity matrix is only 9.6% indicating that the direct control mechanism should be possible.

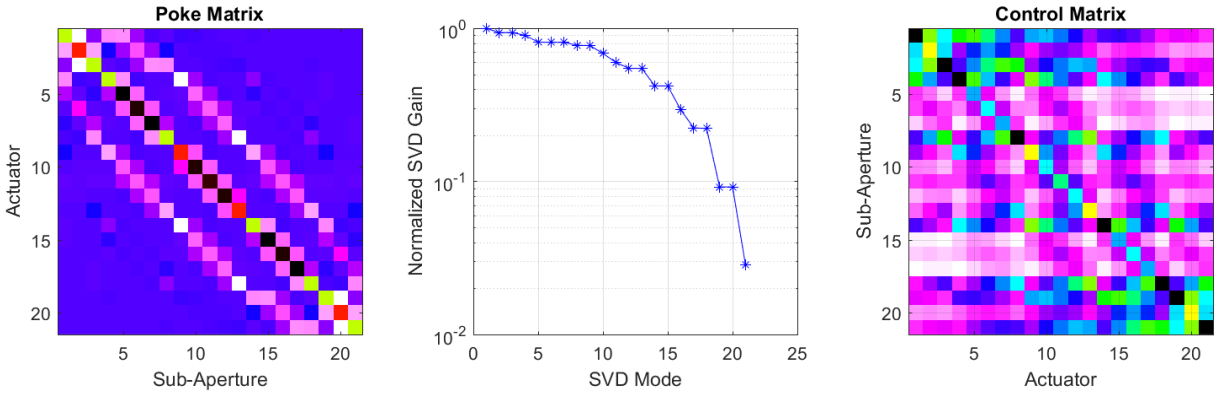

Figure 7: (right) Poke Matrix; (middle) SVD Gains; (right) Control Matrix

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4 Conclusions

We have analyzed the influence functions of a plate-type deformable mirror and shown that they are not perfectly curvature only in shape, but are likely good enough to be used in a direct control strategy in an AO system with a curvature sensor.

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