1994

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA

A NEW PISTON CONTROL STRATEGY FOR SEGMENTED MIRRORS

Prepared by: Philip D. Olivier

Academic Rank: Associate Professor

Institution and Department: Mercer University
Electrical and Computer Engineering

NASA/MSFC:

Laboratory: Astrionics
Division: Optics and Radio Frequency
Branch: Optical Fabrication

MSFC Colleagues: Steven Fawcett
Henry Waites

INTRODUCTION

One approach to the adaptive control of large segmented mirrors[1] involves sending tilt commands to each segment and allowing each segment to minimize the distance between its edges and those of (all or some of) its neighbors. This approach has been adopted in the Phased Array Mirror, Extendible Large Apperture, PAMELA™, testbed now located at NASA's Marshall Space Flight Center, Huntsville, AL. This approach minimizes 1) the communication between the sensors and the segment actuators and 2) computations required by the central controlling computer. When fully implemented, the PAMELA™, concept envisions that each mirror segment will be equipped with integrated computational ability on the same silicon substrate that provides the mirrored surface. This integration is consistant with either analog, digital, or hybrid computational components. In the current PAMELA™ testbed the edge matching computations occur in digital electonics that are not integrated into the mirror segments and the edge matching actuators are voice coil actuators with enhanced damping.

To reduce the cost of sensors, and hence segments, no absolute piston sensors are implemented. This means that the edge sensors that provide the relative position of a segment with respect to three of its six neighbors are the only data used by a segment to adjust its piston. In fact, each segment adjusts its piston according the the following algorithm:

1) $p_{new} = p_{old} + (e_1 + e_2 + e_3)/3$

This algorithm is called the **3-edge inner** algorithm. Currently, a segment does not know its p_{old}, nor does it know e_1, e_2, or e_3 separately. The inner algorithm was chosen by trading off between performance (i.e. edge matching ability or the ability to achieve a smooth surface), implementational complexity, speed, and communication requirements[1] within an analog implementation environment.

This report discusses issues that large segmented mirrors built around the PAMELA™ concept (such as SELENE) will face when they migrate to integrated, and presumably to digital, on-segment computational ability and high bandwidth response. This paper relies on the background in adaptive optics found in Tyson's book[3] and on the specifics of the PAMELA concept found in Rather's summary[1]. An interesting account of a global approach to piston control can be found in the paper by Enguehard and Hatfield[2].

PROBLEMS WITH DIGITAL IMPLEMENTATION

A simulation of a 36 segment PAMELA™ concept mirror under digital piston control with perfect (both speed of response and length of movement) actuators indicates 2 potentially serious problems that result from the attempt to limit global communication. The first problem is **delay induced chatter**, and the second problem is **periphery-to-periphery delay**. Solutions to these problems are suggested that rely only on simple modifications of the existing local communication based on the segment edge sensors. The delay induced chatter problem will appear in any size mirror under true digital control, whereas the periphery-to-periphery delay problem will become worse as the mirror size increases.

Delay induced chatter. Consider the mirror shown in Figure 1 where the sensors are indicated by dots. Suppose that the mirror has adjusted itself correctly according to the inner algorithm and let the horizontally shaded segment be rotated about the x-axis. How long will it take for the moved segment to sense its own motion? Initially it will not be able to sense its own motion because its 3 o'clock sensor will not move relative to its neighbor, whereas its 7 o'clock sensor will move up and its 11 o'clock sensor will move down identical amounts hence the inner algorithm calculates its new piston to be identical to the old piston. Even though the moved segment will not sense its movement, two of its neighbors will sense movement. These segments are numbered 1 in the figure. At the first control cycle after the initial movement, these segments will move to balance their errors. At the second control cycle after the initial movement, neighbors of these segments, segments numbered 2, will sense movement and adjust to balance their errors. At the third control cycle, the initial movement will be sensed by the segment that initially moved. This phenomenon gives rise to a chatter in the output that has a period of 3 itertions. As can be seen in Figure 2, the magnitude of this chatter can be significant i.e. about 5%.

Periphery-to-periphery delay. Consider the mirror shown in Figure 3 with sensors indicated by dots. Suppose that the mirror has adjusted itself correctly according to the inner algorithm and let the shaded segment be moved in either piston or tilt. How long will it take for the segment furthest away to sense its motion? The segment-to-segment communication takes about 9 iterations for initial partial information to arrive. The information is partial because each segment adjusts to the average of its edge errors, so the full impact of the initial motion is not instantaneous on its neighbors. As can be seen in Figure 2 the settling time is about 20 iterations.

These problems are less significant in analog implementations for two reasons. First, the delay induced chatter will be reduced by any damping in the analog actuators and second, some communication is virtually instantaneous (i.e. about as fast as the speed of sound in the material). But in a digital implementation the delay induced chatter will be significant for any size mirror regardless of the iteration cycle time and the periphery-to-periphery delay will be important once the mirror exceeds some size that is dependent on the iteration cycle time. For example, a 200,000 segment mirror has about 400 rings of segments. It will take 800 iterations for preliminary information to traverse the structure. If the piston loop must have a bandwidth of 1 kHz (settling time significantly less than 10^{-3} seconds) and if it takes 4 periphery-to-periphery exchanges for the suface to settle down, the each segment must perform its calculations (3 additions and 1 division) significantly faster than $(1/1.6)*10^{-6}$ seconds. The periphery-to-periphry delay has been recongnized and it has been suggested that for mirrors with very many segments, that an enhanced algorithm[1] be implemented that includes absolute piston sensing and command for some segments that are distributed throughout the mirror.

SOLUTIONS

This report suggests solutions to these two problems and evaluates the solutions via simulation. The solution to the delay induced chatter is called **algorithmic damping**, and the solution to periphery-to-periphery delay involves the introduction of **spines**.

Algorithmic Damping. The solution to the delay induced chatter problem is to introduce damping into the piston control problem. For each segment adjust the piston according to

$$2)\quad p_{new} = p_{old} + \epsilon(e_1 + e_2 + e_3)/3 \qquad 0 < \epsilon < 1$$

When $\epsilon = .99$ simulations indicate that oscillations remain but damp out. For $\epsilon = .9$ simulations indicate that oscillations virtually disappear, see Figure 3.

Spines. Consider some segments that do not look at three of their neighbors. These segments take their commands directly from only one of their neighbors. The motivation for this is to speed communication through the structure. For this study 3 spines that radiate from the center were investigated, see Figure 4. Figure 5 shows the simulation results.

Switching. Simulations were conducted that investigated the initial use of spines followed by switching to the current inner algorithm. The switches occurred after 10 and 20 iterations. This investigation, while preliminary, indicates that it is a potentially useful approach.

Comparisons. The results are summarized in the following table.

	smoothness	max(p) - min(p)	iterations
theoretical best	.0213	.0850	NA
current	.0229	.1097	20
spines	.0228	.1052	13
switch-10	.0229	.1098	14
switch-20	.0229	.1098	21
	$*10^{-3}$	$*10^{-3}$	eyeballed 95% settling time

The settling time when spines are used is significantly better than the inner algorithm. When the switch was made at the 10 iteration, the settling time went to 13, which is still better than the current algorithm. The surface smoothness is virtually identical regardless of the algorithm used.

CONCLUSIONS

Three conclusions can be drawn from this preliminary study: first, that a digital implementation will require 'algorithmic damping' to reduce delay induced chatter; second, the use of spines will allow larger mirrors to be controlled quicker without the introduction of absolute piston commands to reference segments; and third, that switching from the use of spines to independent segments appears to be useful strategy for large mirrors. Such switching should also be useful when using reference segments. That is, a segment might initially be a reference segment and receive an absolute piston command to speed up control communications, and then after a few iterations it might become an independent edge matching segment to enhace surface smoothness.

QUESTIONS

This study suggests several questions. Among them:

Should spines branch out for larger mirrors?

What percentage of the segments can/should be on a spine?

How many segments can be controlled with spines?

What is the optimal switching strategy?

REFERENCES

1. J. D. G. Rather, Power Transmission Optics Issues: SELENE Optics, NASA report, May 1991.

2. S. Enguehard and B. Hatfield, An exact analytic solution to segmented-mirror adaptive-optics control, J. Opt. Soc. Am. A/Vol. 11, No. 2/ Feb. 1994, pp. 874 - 879.

3. R. K. Tyson, **Principles of Adaptive Optics**, 1991, Academic Press, Inc, Boston.

FIGURES

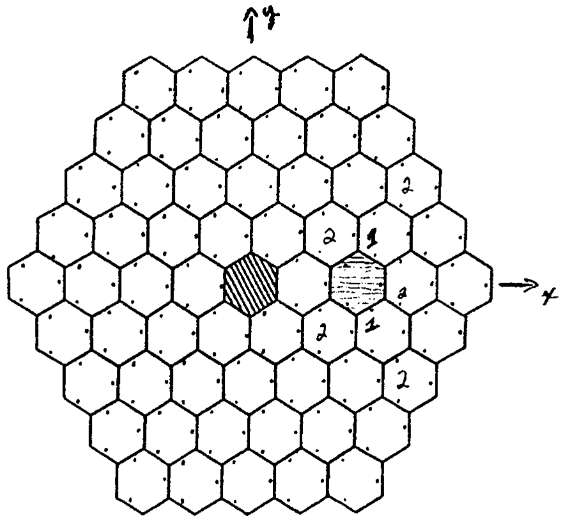

Figure 1. Delay induced chatter explanation

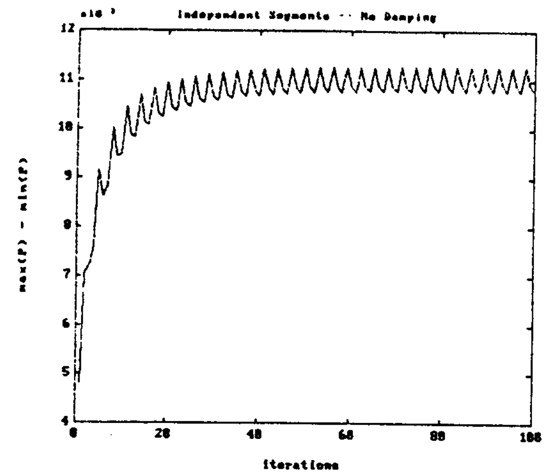

Figure 2. Delay induced chatter simulation

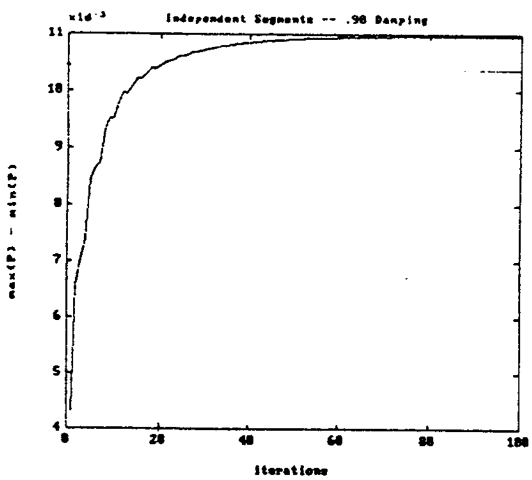

Figure 3. ϵ = .9 algorithmic damping

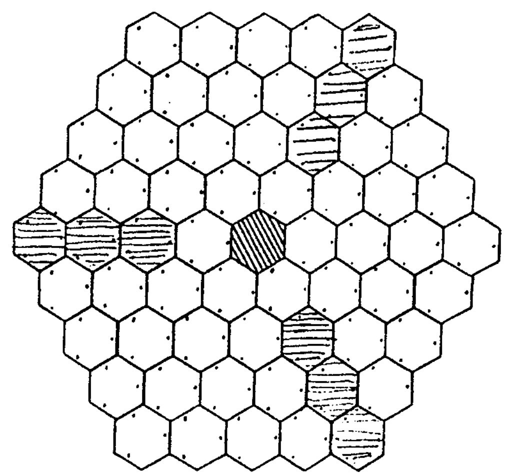

Figure 4. 3 Radial Spines

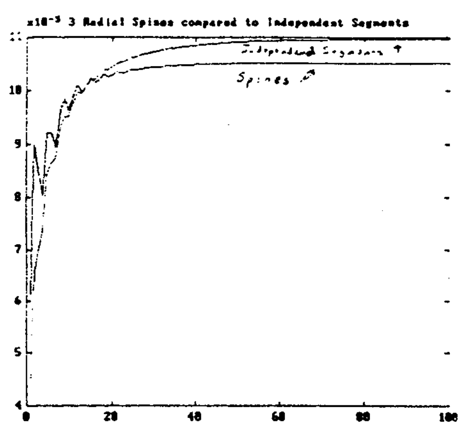

Figure 5. 3 Radial Spine simulation results