Deriving Convergent Actuator Influences within an Unstable Resonator for Application to the Solid State Heat Capacity Laser (SSHCL) project

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Hosted by the Adaptive Optics Group at Lawrence Livermore National Laboratories

Overview

- Introduction to SSHCL
- Deriving a Control Algorithm
- Extrapolating Impulsive System Matrix to Converged System Matrix

The Solid State Heat Capacity Laser Project

Heat capacity mode-- lasing medium is not cooled while lasing

SSHCL -- combine HCL with adaptive resonator

Design goals:
- High power (HC)
- Compactness (HC)
- High beam quality (AO)

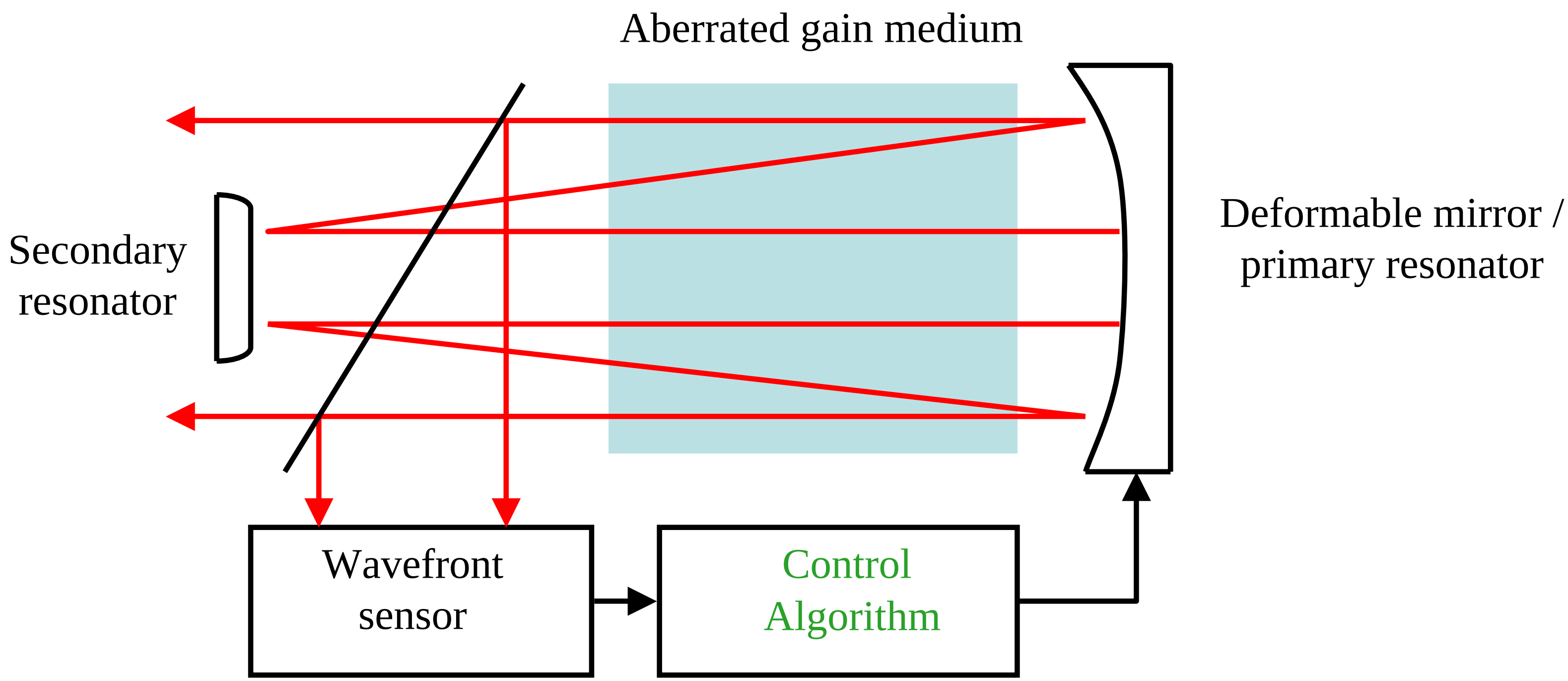
Future (100KW)

Potential applications: industry, military (working with HELSTF), xenobiology

Current (10KW)

Current system specs:
- Nd:Glass slabs (gain medium)
- 1053 nm wavelength
- 500 J/ ~300μs
- >20X diffraction-limited without AO, ~5-6X with AO (goal of <3X)

Adaptive Optics Setup used in the SSHCL



Aberrations still occur, due to thermal stresses/ static defects in gain medium

Uses unstable resonator w/ M=1.5, worsens effects of aberrations

Use intracavity adaptive optics to directly control mode shape, instead of only phase

Deriving AO Control Algorithm for SSHCL

Given an aberration measured by the WFS, what voltages should be applied to the DM (deformable mirror) to correct it?

Resonator output phase for a given DM phase:

$$\phi_{out}(x) = MW(z_{DM})M^{-1}\phi_{DM}(x)$$

- M - aberration polynomial mode construction operator
- W - mode influence coefficients, given the geometry of the resonator (diagonal matrix)

WFS measurement for a given DM voltage vector:

$$\vec{s}_{wfs} = FMW(z_{DM})M^{-1}D\vec{v}_{DM} \equiv A\vec{v}_{DM}$$

- F - finite difference operation representing WFS gradient operation
- D - influence of actuators of DM
- A - system matrix for that geometry

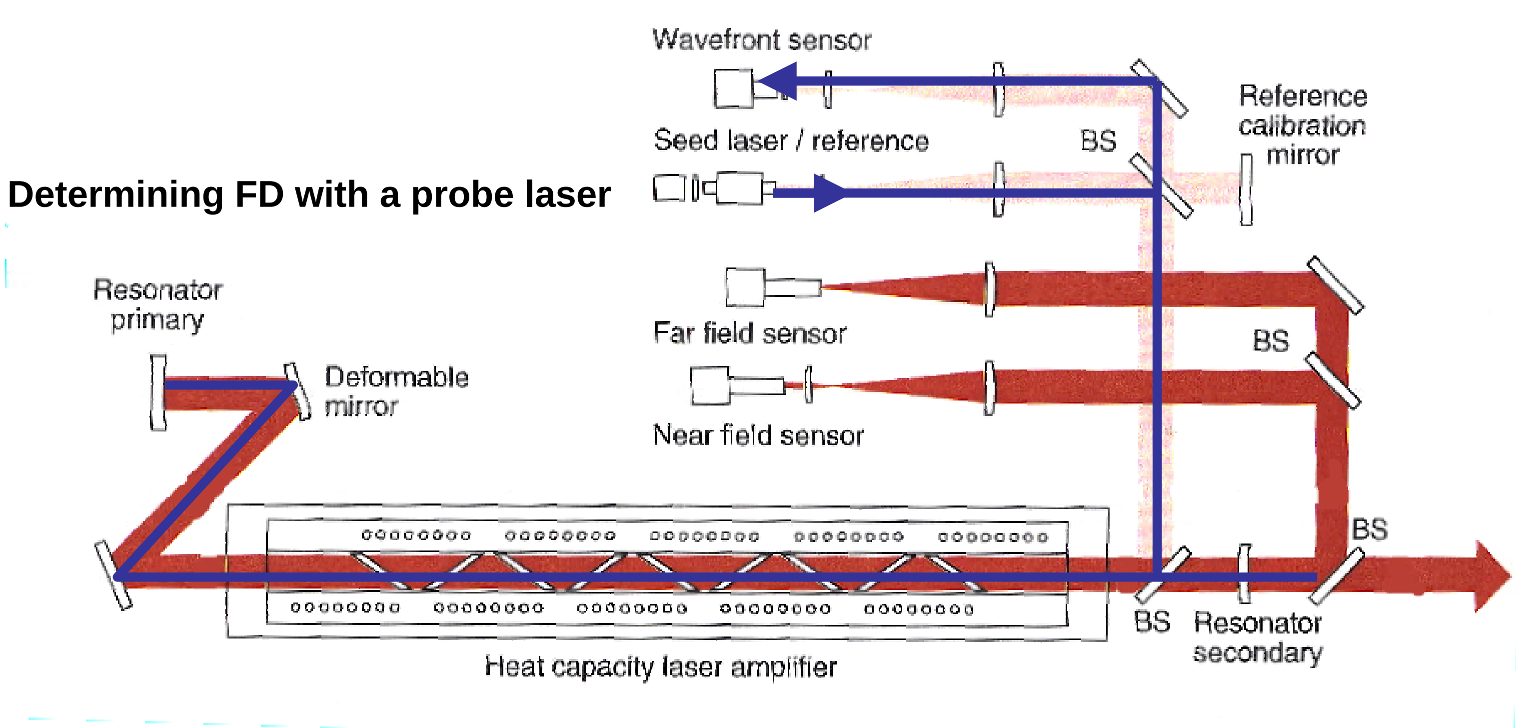
Use the least squares inverse to the system matrix:

$$\vec{v}_{DM} = A^{+}\vec{s}_{wfs}$$

Deriving AO Control Algorithm for SSHCL

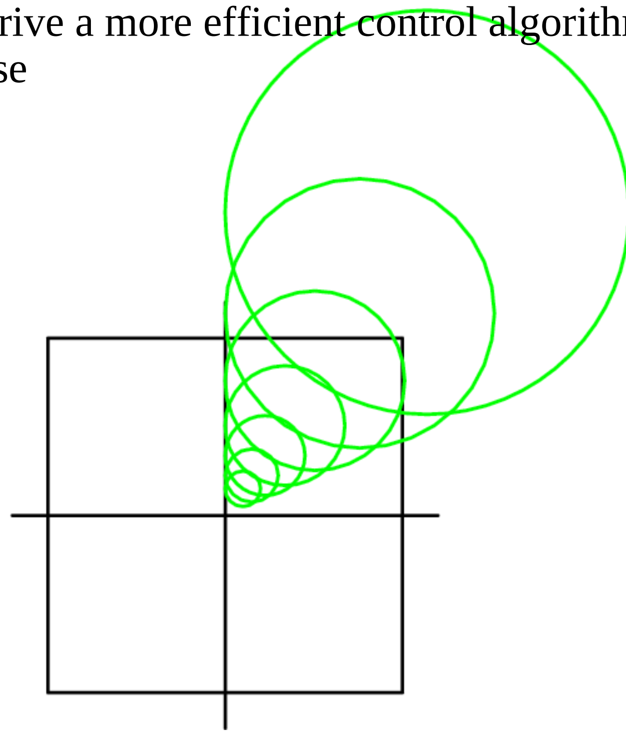
- Ideal method for finding A: Measure convergent modal influence of each actuator using multipass resonation.
- Current: Assume A=FD (theoretically should converge). Measure A using a single pass through the system.
- Compromise: Detailed simulation to determine MWM^{-1}, or, numerical extrapolation of the system matrix gathered using the current method

Determining FD with a probe laser

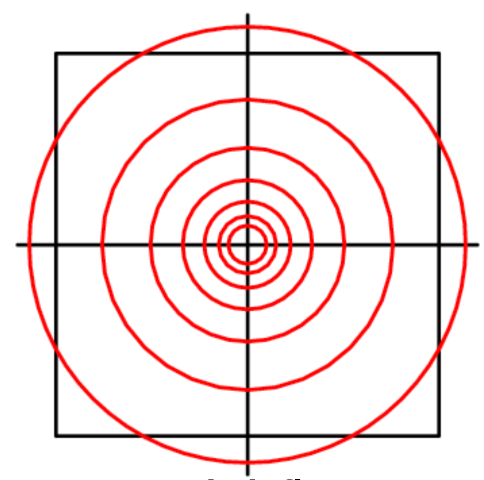


Effect of resonation on Converged Actuator Influence Functions

- Impulse effect of actuator pushes are magnified, shifted, and summed-- shape and magnitude of converged wavefront are highly dependent of distance of actuator from optical axis
- Current testing cannot reveal converged influence function, because beam is not resonated.
- Can derive a more efficient control algorithm if know time averaged (converged) response



Off-axis influence function resonation



On-axis influence function resonation

Method for deriving effective modal influence of the actuators from the current, impulsive system matrix

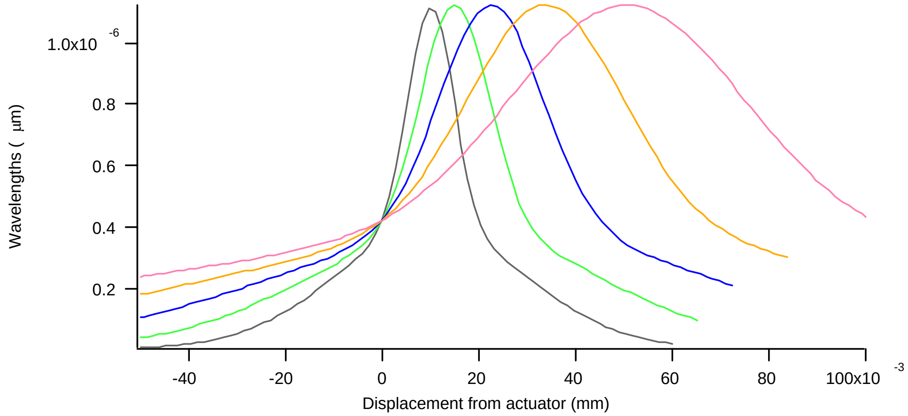
1. Use current system matrix (actuator push vs. centroid slope data) to fit a DoG to 1d influence function of actuator in horizontal direction (due to DM geometry, only sampling direction)

$$D(x) = A_0 e^{-(b_0 x)^2} - A_1 e^{-(b_1 x)^2}$$

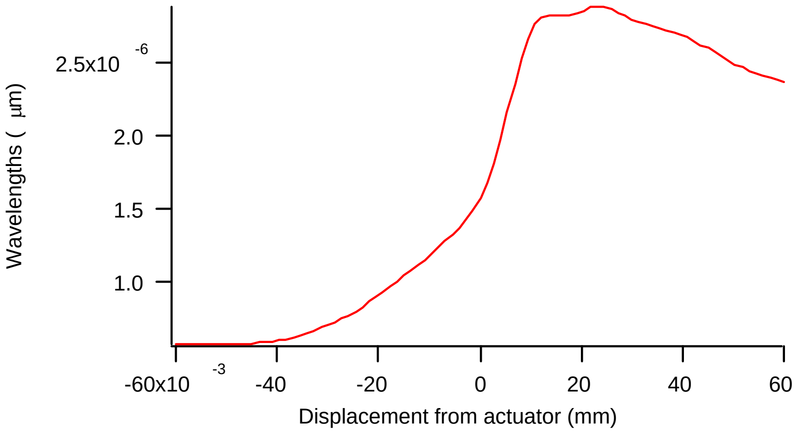
2. Exploiting 10% influence drop b/w adjacent actuators, extrapolate convergent 1d influence function to 2d influence function

3. Magnify the shift and width of the DoG according to the actuator's location 30 times (effectively infinity), then sum together

Multiple resonations of a 1d actuator influence function



Resultant modal influence function



Extrapolating to a 2d impulse influence function

closest actuators form a pseudo-hex

linear interpolation using the fact that actuator influence falls off to 10% of peak value at nearest actuators

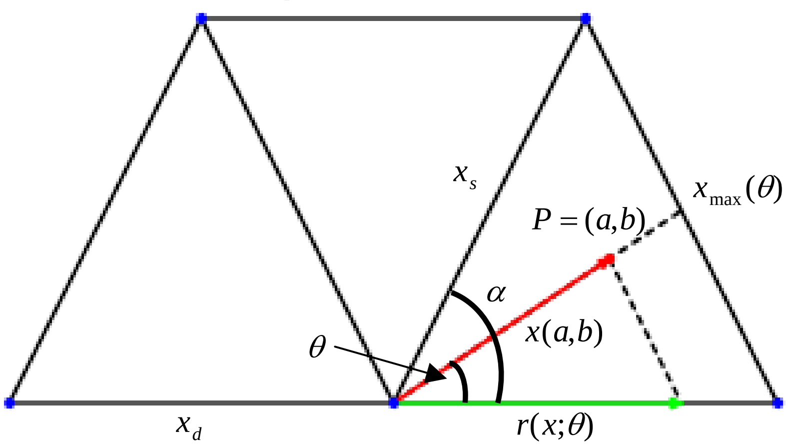
$$x(a,b) = \mathrm{sgn}(b)\sqrt{a^2 + b^2}$$

$$f_{2\mathrm{d}}(a,b) = f_{1\mathrm{d}}(r)$$

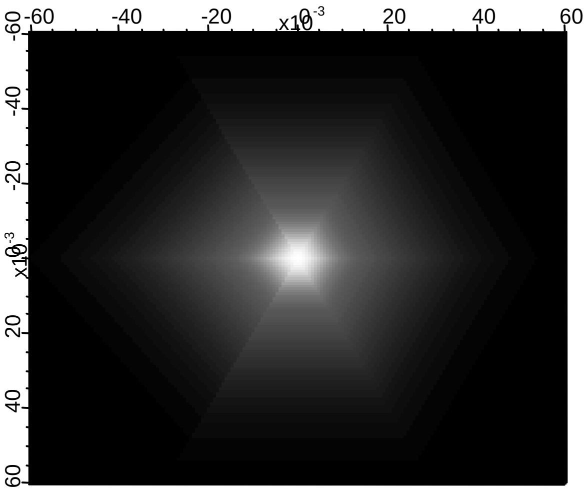
$$r(x;\theta) = \frac{x}{x_{\max}(\theta)}$$

$$x_{\max}(\theta) = \frac{x_d x_s \sin(\alpha)}{\sin\left(\theta + \arcsin\left(\frac{x_s \sin(\alpha)}{\sqrt{x_d^{\ 2} + x_s^{\ 2} - 2x_d x_s \cos(\alpha)}}\right)\right)\sqrt{x_d^{\ 2} + x_s^{\ 2} - 2x_d x_s \cos(\alpha)}}$$

Interpolation scheme

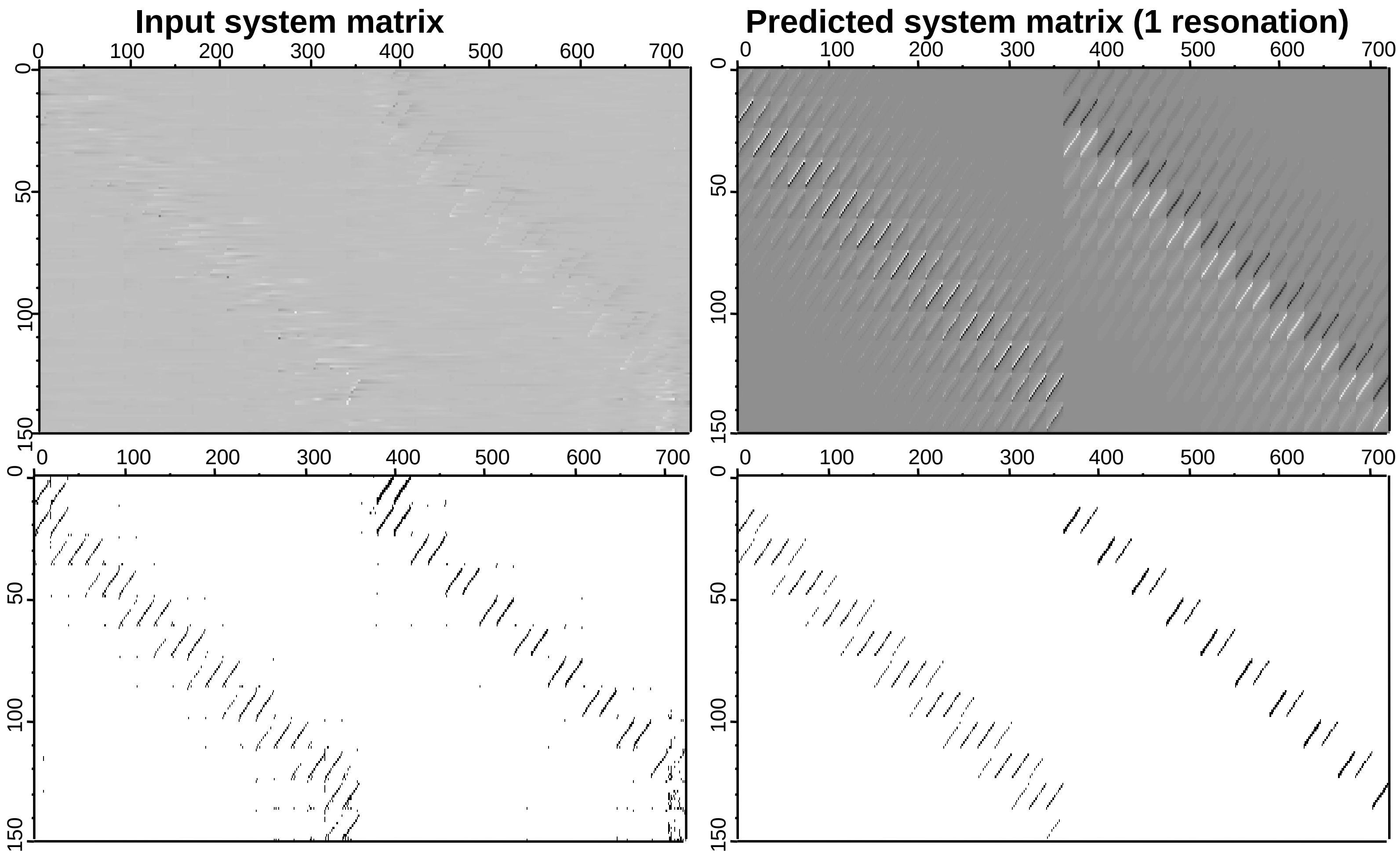


2d influence function



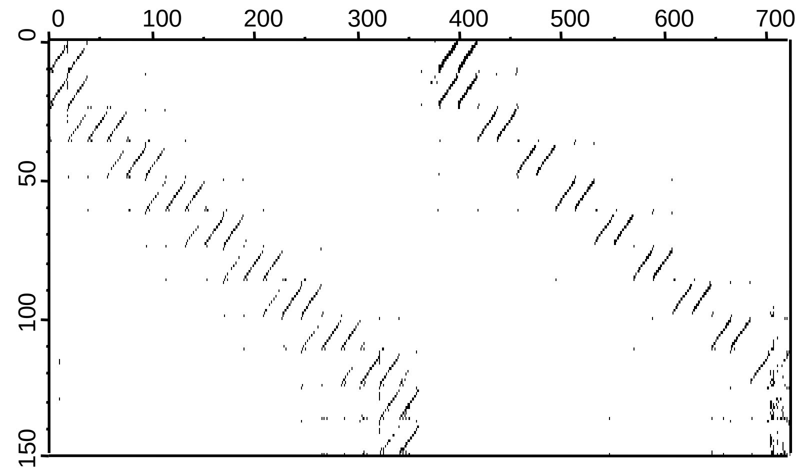
Evaluating accuracy of algorithm

• intensity variations (due to noise?), but same pattern

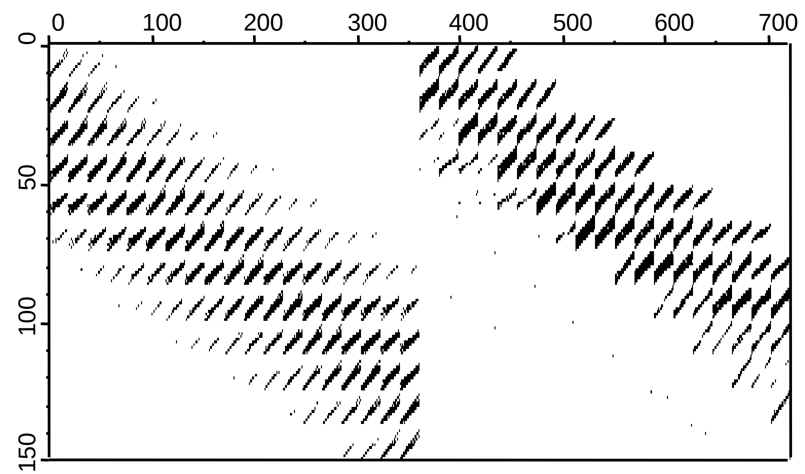


Comparisons and Conclusions

- Much difference between the converged influence, and the impulse influence
- Since the converged influence accounts for effects of multiple passes through the resonator on the beam, it should lead to a more effective control algorithm
- Future directions: use more resonations, test the hypothesis that the converged influence provides a more efficient control algorithm, see effect of interpolative schemes on system matrices, …



Impulsive system matrix



Converged system matrix

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References

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Technical Program Review: "Development of Adaptive Resonators for Solid State Heat Capacity Lasers". Brent Dane, Jim Brase, Erik Johansson, Scott Fochs, Mark Henesian, Jason Gwo.

Internal Document "The adaptive unstable resonator-- theory and design". James M. Brase, Erik M. Johansson

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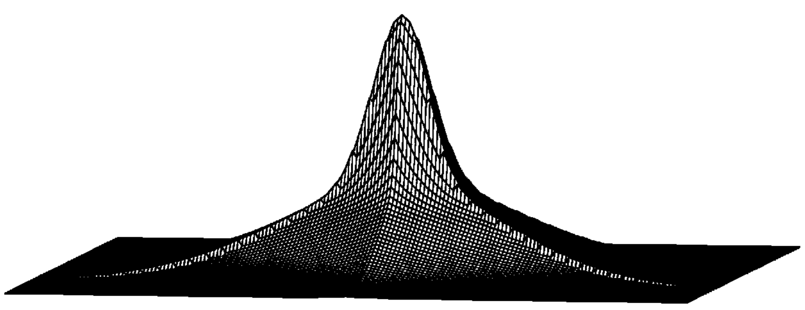
Finding modal influence functions (1)

The modal influence function is a linear superposition of appropriately magnified impulse influence functions

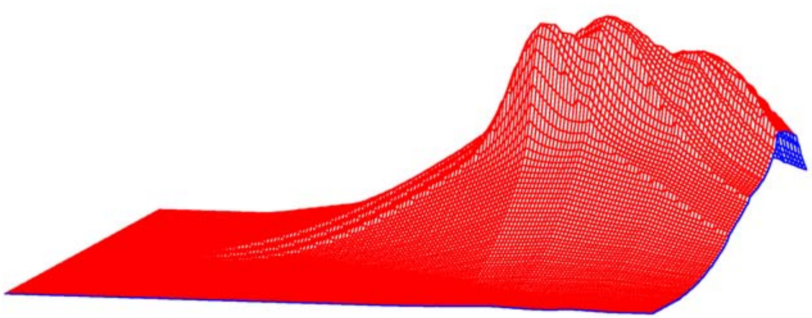
$$D_{\mathrm{modal}}(x) = D(x) + M(D(x)) + M(M(D(x)) + \ldots$$

Expand the width of the influence function without changing the amplitude and magnify the displacement of the influence function from the optical axis:

$$D(x) = A_0 e^{-(b_0(x-x_c))^2} - A_1 e^{-(b_1(x-x_c))^2} \xrightarrow{M} D_M(x) = A_0 e^{-(\frac{b_0}{M}(x-Mx_c))^2} - A_1 e^{-(\frac{b_1}{M}(x-Mx_c))^2}$$

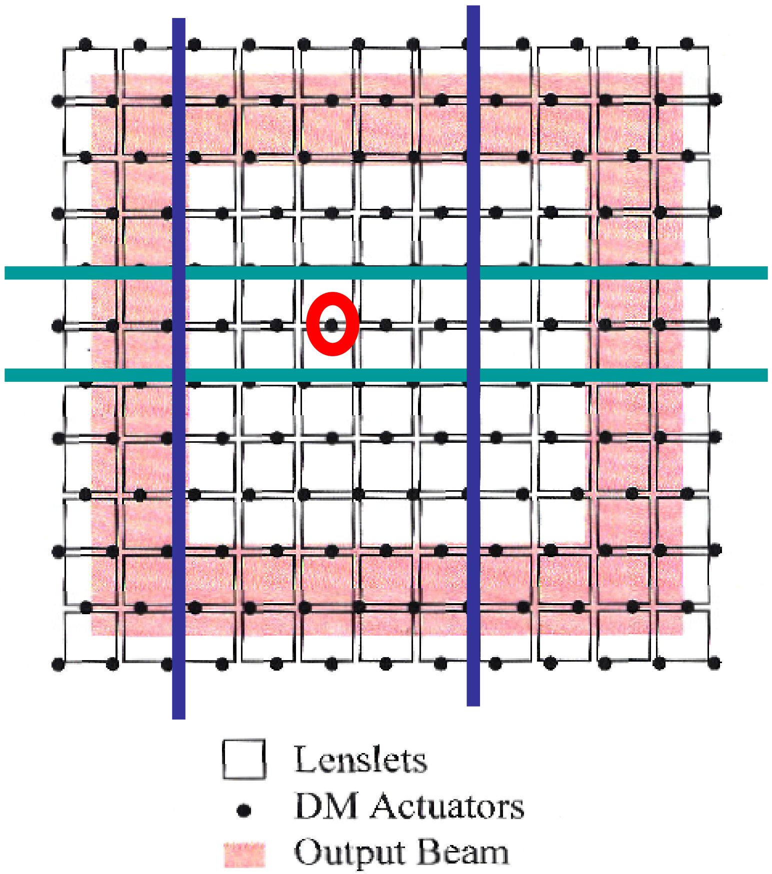


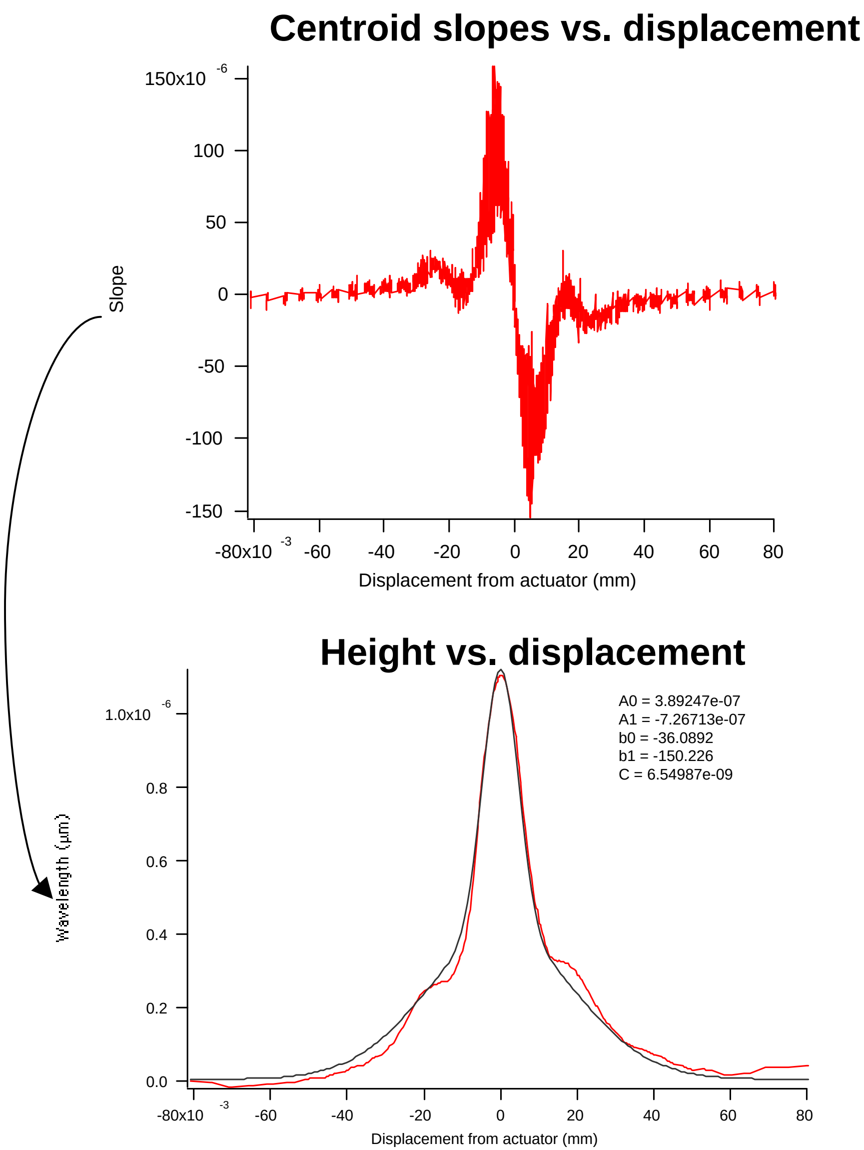
Impulse Influence function



Modal influence function

Sampling/Fitting the 1D influence function

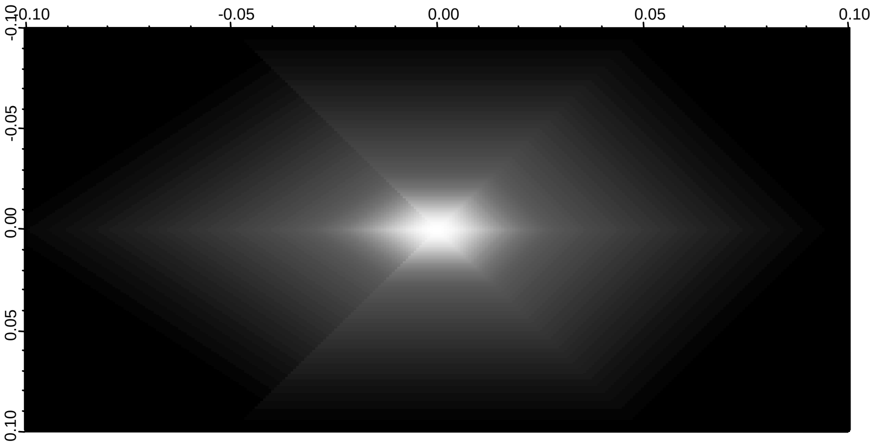




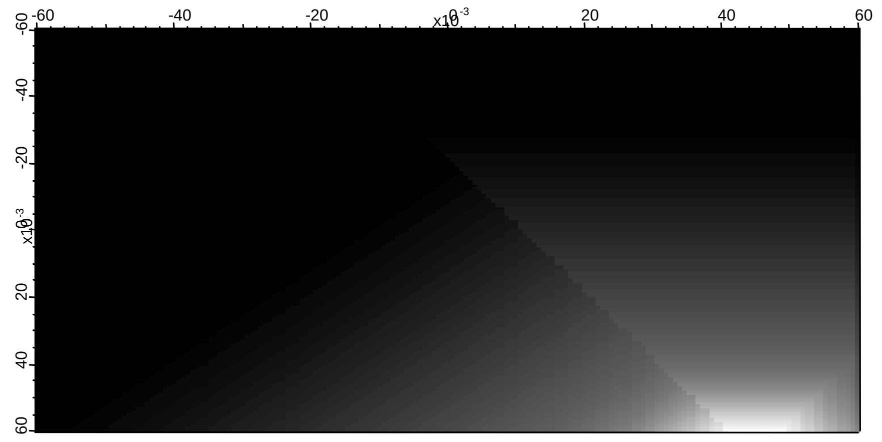
Due to pseduo-hex geometry, can only sample meaningfully in the x-direction

Smoothness of fit to a DoG varies as increase sampling window width

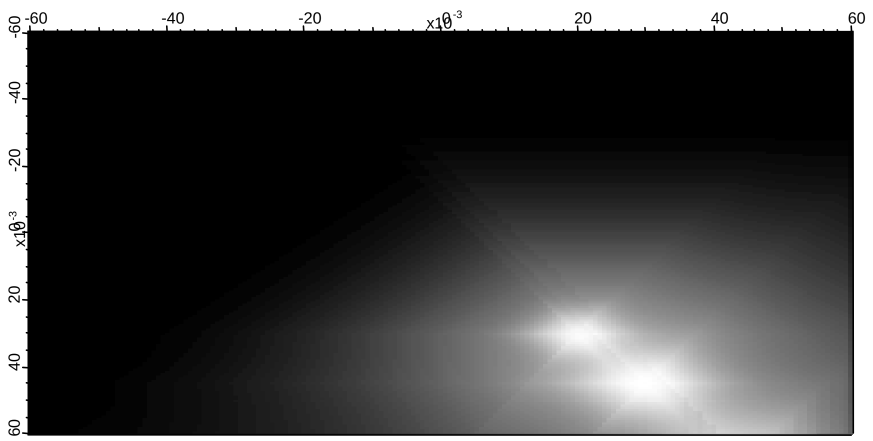
Finding modal influence functions (2)



Calculate a centered impulse with the necessary width for this resonation



Shift the impulse with the appropriate offset (Mx, My)



Keep a running sum of the shifted impulses