Design optimization of actuator layouts of adaptive optics

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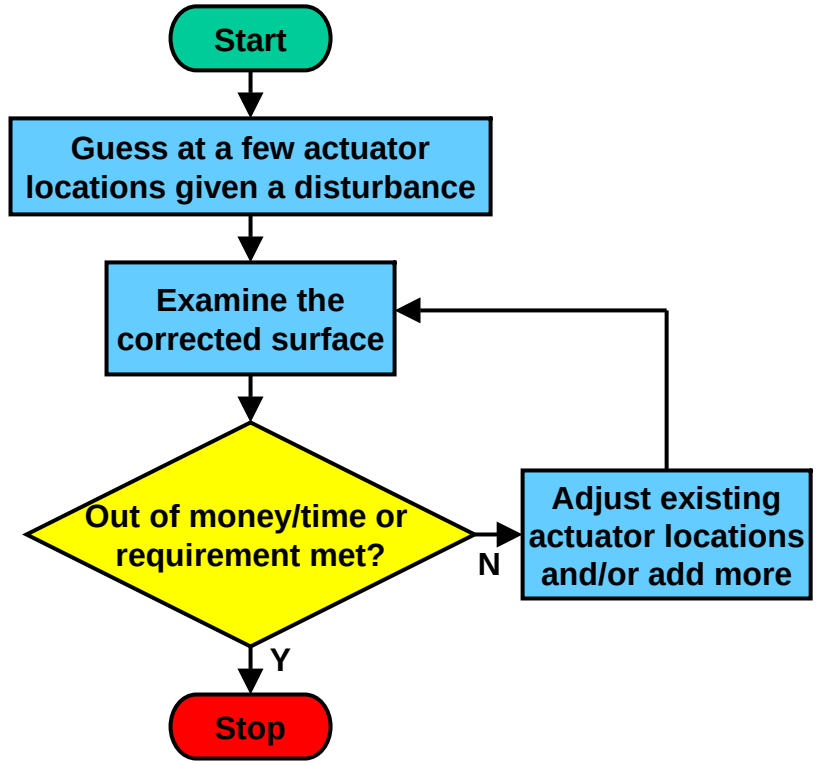
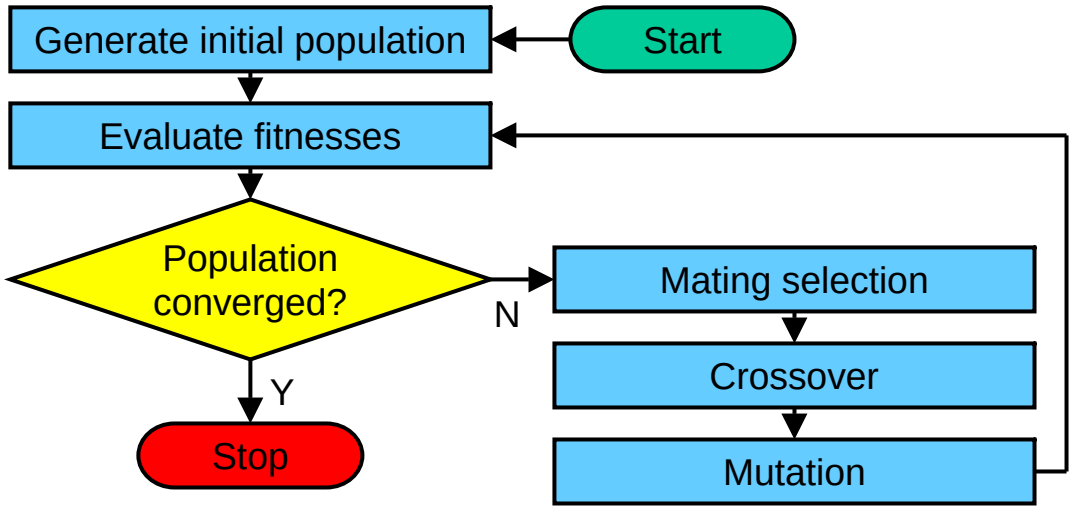
Objective

- Development of actuator layouts has been manual and iterative
  - Time consuming
  - May not result in least number of actuators for same performance
  - Hard to handle multiple disturbances
  - Not designed to find an optimum
- Need automated tool to quickly find actuator layout at or near global optimum
  - Allow enforcement of symmetry in actuator layouts
  - Allow certain actuators to be fixed in location (e.g., displacement actuators at mounts)
  - Limit the number of actuators



Genetic Algorithm



Actuator layout representation

- Chromosome of 1's and 0's indicates which actuators exist in a layout

		Genes (Actuators)								
		1	2	3	4	5	6	7	8	9
Individuals (Actuator Layouts)	1	1	0	0	1	0	0	0	1	1
	2	0	1	0	1	0	0	1	0	1
	3	1	0	0	1	1	0	1	0	0
	4	1	1	0	0	1	1	0	0	0

Generate initial population

- Randomly select even number of actuator layouts with fixed number of actuators
- Each coded by chromosome

Evaluate fitnesses

- Compute the corrected surface RMS error for each actuator layout in the population

Convergence evaluation

- Compare improvement of corrected surface RMS error over generations

Mating selection

- A pool of mating actuator layouts is generated by random selection from population weighted by reciprocal of corrected surface RMS error

Crossover

- Genes from mating actuator layouts are exchanged with ~60% probability to create next generation
- Prior generation discarded

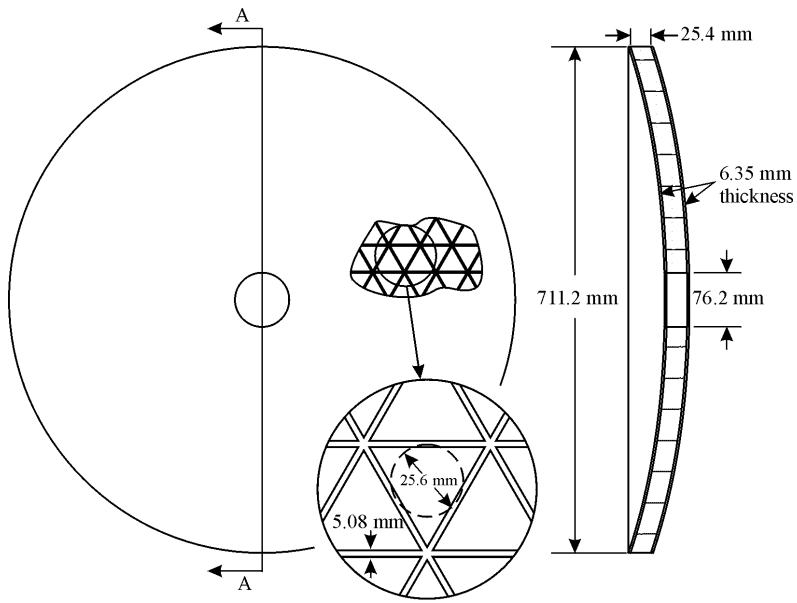
Mutation

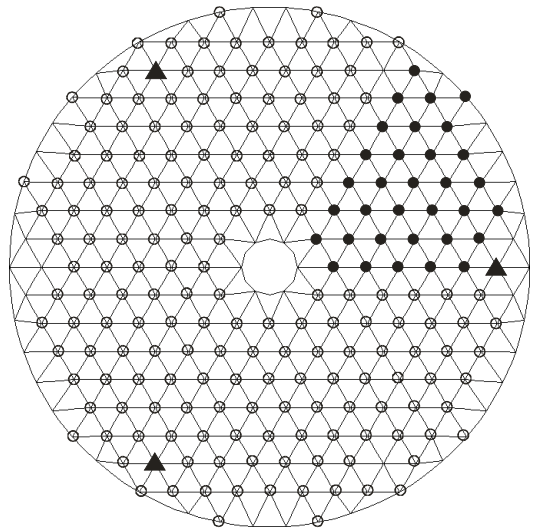
- Genes are changed at random with very low probability (~3%)
- Actuator 3 above will never be considered without mutation

Reference 1

Example - Problem Statement

- Environmental disturbances
  - Gravity along optical axis
  - Isothermal 20C temperature drop
  - Front-to-back 0.15C temperature difference
  - Combination of all of the above
- Candidate actuators
  - 210 candidate actuator locations
  - 35 master locations for six-fold symmetry
  - 3 fixed location displacement actuators
- Objective
  - Find best layout of 18 actuators
  - 6545 possible layouts of 18 actuators each

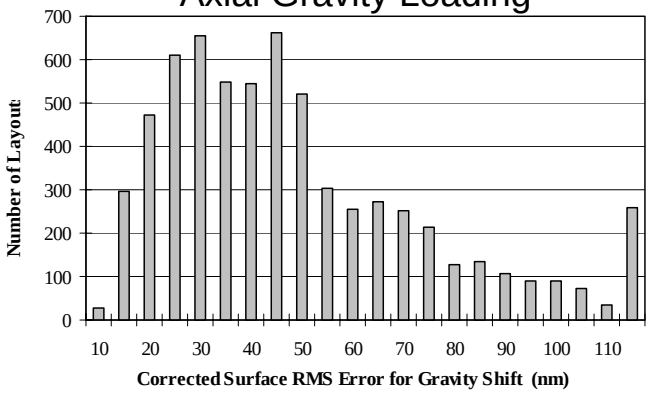




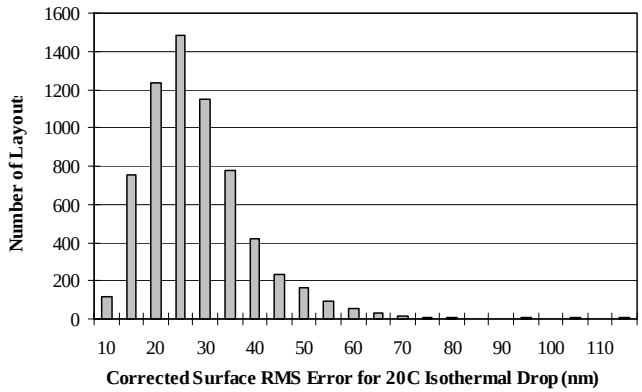
Example - Full Permutation Results

- Full permutation results are baseline for comparison to genetic algorithm
  - Each load case's evaluation of 6545 layouts takes 28 minutes of CPU time
  - Number of layouts increases exponentially with number of actuators

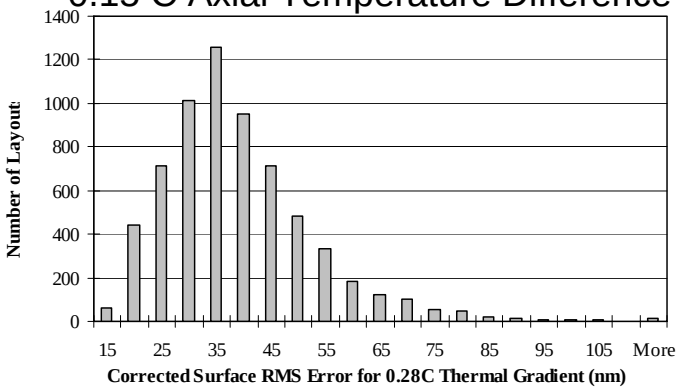
Axial Gravity Loading



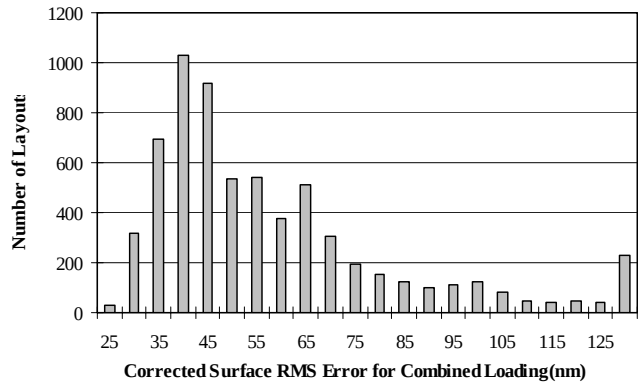
Isothermal 20C Temperature Drop



0.15 C Axial Temperature Difference



Combined Loading

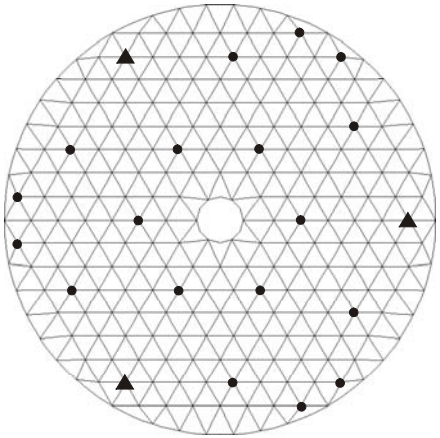


Example - Genetic Optimization Results

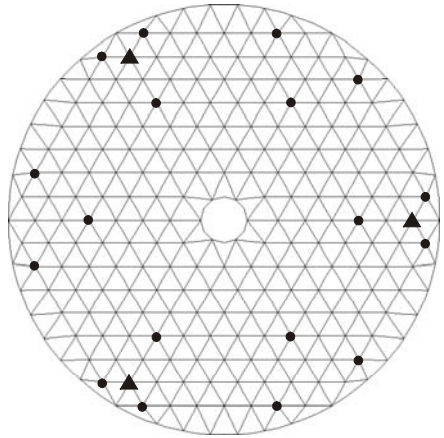
- Optimization executed four times for each load case
- Each execution takes a few seconds of CPU time
- Detection of designs close to global optimum is outstanding

Operational Disturbance	Genetic Result #1	Genetic Result #2	Genetic Result #3	Genetic Result #4	Best Genetic Result	Global Optimum	Global Average
Gravity Variation	8.4 nm	9.1 nm	10.1 nm	8.5 nm	8.4 nm	7.0 nm	47.8 nm
20 °C Isothermal Temperature Drop	10.8 nm	9.5 nm	10.6 nm	12.2 nm	9.5 nm	6.1 nm	25.9 nm
0.15 °C Front-to-Back Axial Temperature Difference	17.7 nm	18.1 nm	13.9 nm	15.6 nm	13.9 nm	10.6 nm	36.6 nm
Combination of Above	27.2 nm	26.6 nm	24.2 nm	25.4 nm	24.2 nm	21.6 nm	57.3 nm

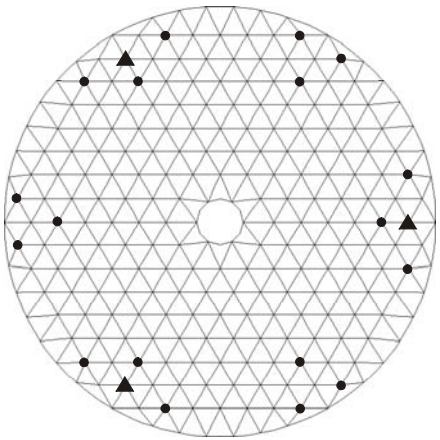
Example - Optimum Actuator Layouts



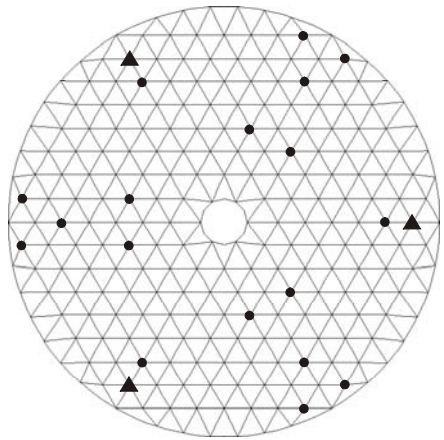
Optimum Layout for Correction
of Gravity Loading



Optimum Layout for Correction
of Isothermal Temperature Changes



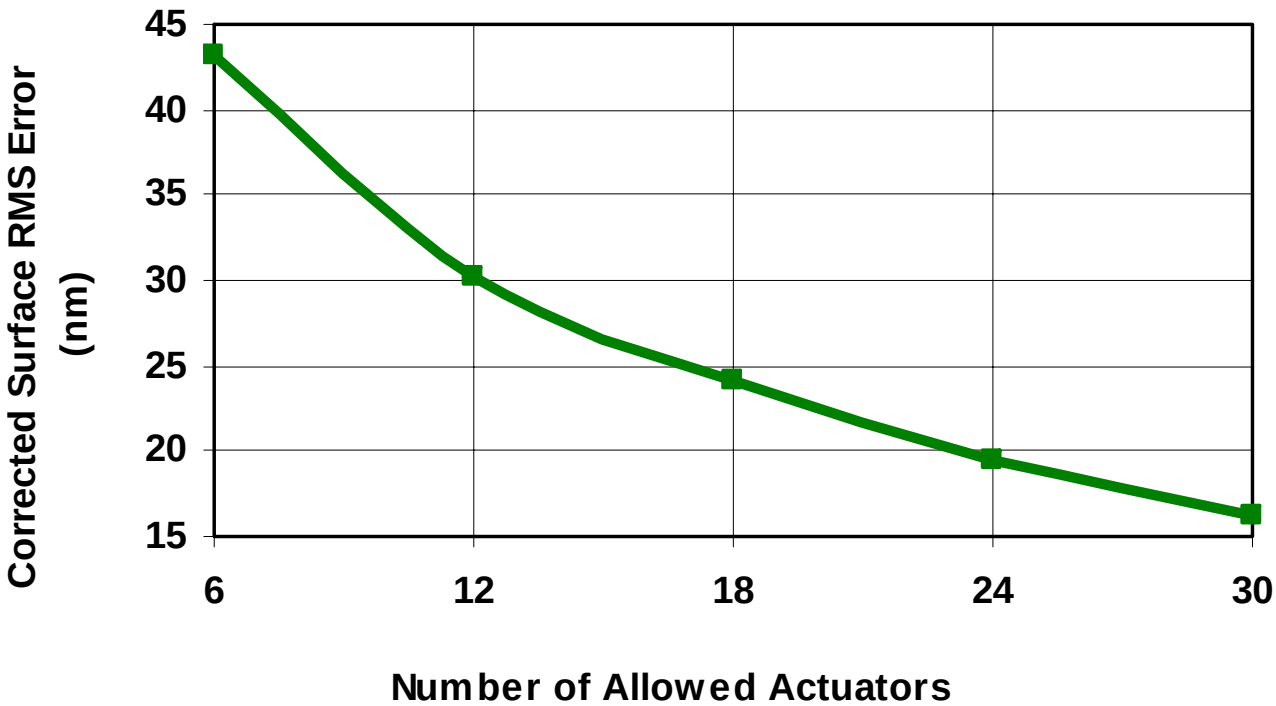
Optimum Layout for Correction
of Axial Thermal Gradient



Optimum Layout for Correction
of Combined Loading

Example - Number of Actuators Trade

- Genetic optimization performed for various numbers of actuators allowed in the layout
- Allows study in how many actuators needed to meet requirement
  - Example: 18 actuators required to meet 25 nm corrected surface RMS



Conclusion/References

- Genetic optimization is well suited for actuator layout design
  - Fast
  - Reliably effective
- Capability to be released in SigFit 2005 this summer
- Future work
  - More flexible support symmetric actuator layouts
  - Combine actuator layout optimization with structural optimization

- References

1. Goldberg, David E., **Genetic Algorithms in Search, Optimization & Machine Learning**, Addison-Wesley-Longman, Boston, MA (1989).

2. Doyle, Keith B., Victor L. Genberg , Gregory J. Michels, **Integrated Optomechanical Analysis**, SPIE Press, Bellingham, WA (2002).

3. Michels, Gregory J. et al., “Design optimization of actuator layouts of adaptive optics using a genetic algorithm”, SPIE Vol. 5877 (22), San Diego, CA, August, 2005.