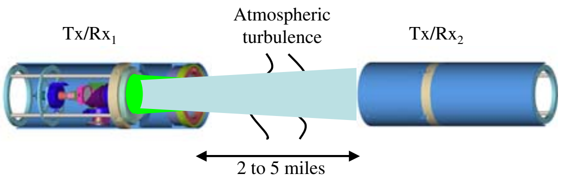
VLSI for Adaptive Optics

Marc Cohen, Institute for Systems Research & Intelligent Optics Laboratory
(mhcohen@isr.umd.edu)

Objectives

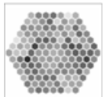
- The Intelligent Optics Laboratory is developing low-power, compact, free-space laser communication systems for real-time high-resolution video transmission
- These systems must actively mitigate wavefront phase distortion due to atmospheric turbulence over near ground 2 to 5 mile propagation paths.
- To accomplish this, it is essential to develop **VLSI controllers** that control wavefront correctors such as liquid crystal spatial light modulators, MEMS mirrors and bi-morph piezoceramic mirrors and **VLSI sensors** that can measure laser beam position and laser beam "quality" in real-time



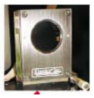
Active Optical Wavefront Control Elements

- We use these devices to alter the wavefront phase of the launched and/or received laser beam

MEMS devices with up to 1024 individual piston-type mirrors and bandwidth ~ 7KHz



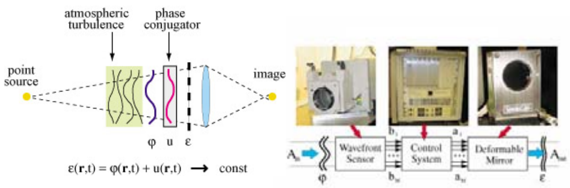
Liquid crystal spatial light modulators with ~ 127 pixels and bandwidth ~ 10Hz



Piezoceramic deformable mirrors with ~ 5 to 20 degrees of freedom and bandwidth ~ 1KHz

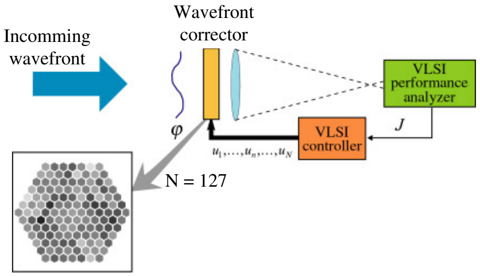
Conventional Adaptive Optics Systems

- Model-based approach works well for a *point source* such as a distant star, but not for distributed objects at "closer" range
- Measure intensity with a Shack-Hartmann sensor and then reconstruct phase using least-squares or SVD techniques (*computationally intensive*)

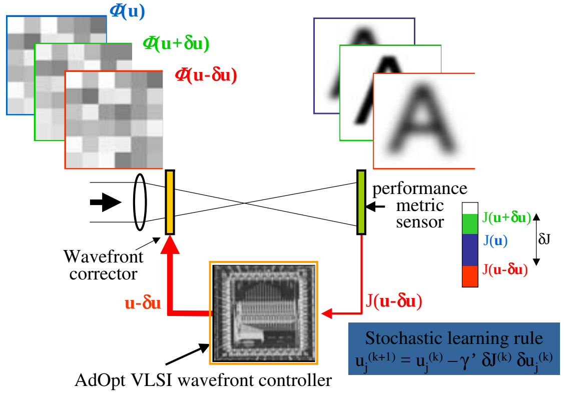


A Model-Free Approach to Adaptive Optics

- Advantages
  - ✓ can deal with distributed objects (*anisoplanatic conditions*)
  - ✓ turbulence can occur over the entire propagation path
  - ✓ control method is independent of the number of control channels
  - ✓ accommodates wavefront correctors of all types
  - ✓ computationally simple

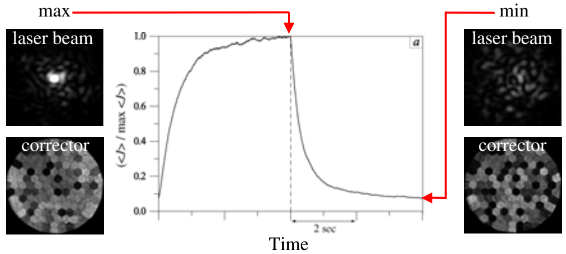


Adaptive Optics VLSI Controller: Metric Optimization by Stochastic Parallel Gradient Descent



Wavefront Control using 127 Element SLM

maximized then minimized J(**u**) using Bernoulli perturbation statistics $\delta u_j^{(k)}$

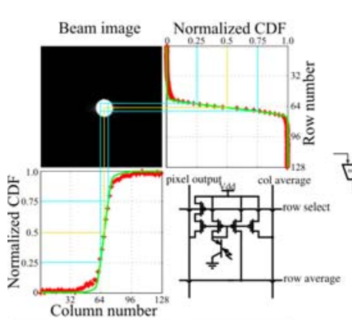


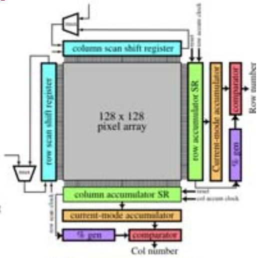
- Enormous convergence speedup can be achieved by tailoring the perturbation statistics to match the statistics of the atmospheric turbulence

Measuring the Metric J(u)

- The metric should be task-specific:
  - for this particular laser communication task, we need real-time measurements of:
    - Beam centroid location for wavefront tip/tilt control
    - Beam intensity profile for wavefront focus control
- To this end, we have designed a special purpose imaging and tracking sensor with an optical window in its center. Beam Profile Metric sensor outputs are:
  - A 128 by 128 pixel image at a refresh rate of 30 frames/sec.
  - Beam centroid location {Xc,Yc} at 10KHz
  - A scalar measure of 2-D beam intensity profile at 10KHz

Principal of Operation

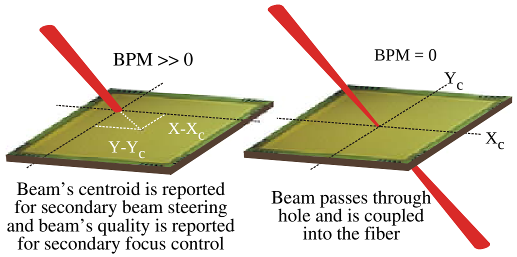




	Centroid	Beam Quality
Measured	69,66	12.2
Calculated	68,66	12.2

Chip photo

Concept



Beam's centroid is reported for secondary beam steering and beam's quality is reported for secondary focus control

Beam passes through hole and is coupled into the fiber

Bibliography

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Center for Satellite and Hybrid Communication Networks
Battelle