Position sensing in Adaptive Optics

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Durham Smart Imaging

Active Optics

Adaptive Optics

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Active Optics

- Relaxing the mechanical rigidity of a telescope support structure

- Compensating with actively aligned mirrors

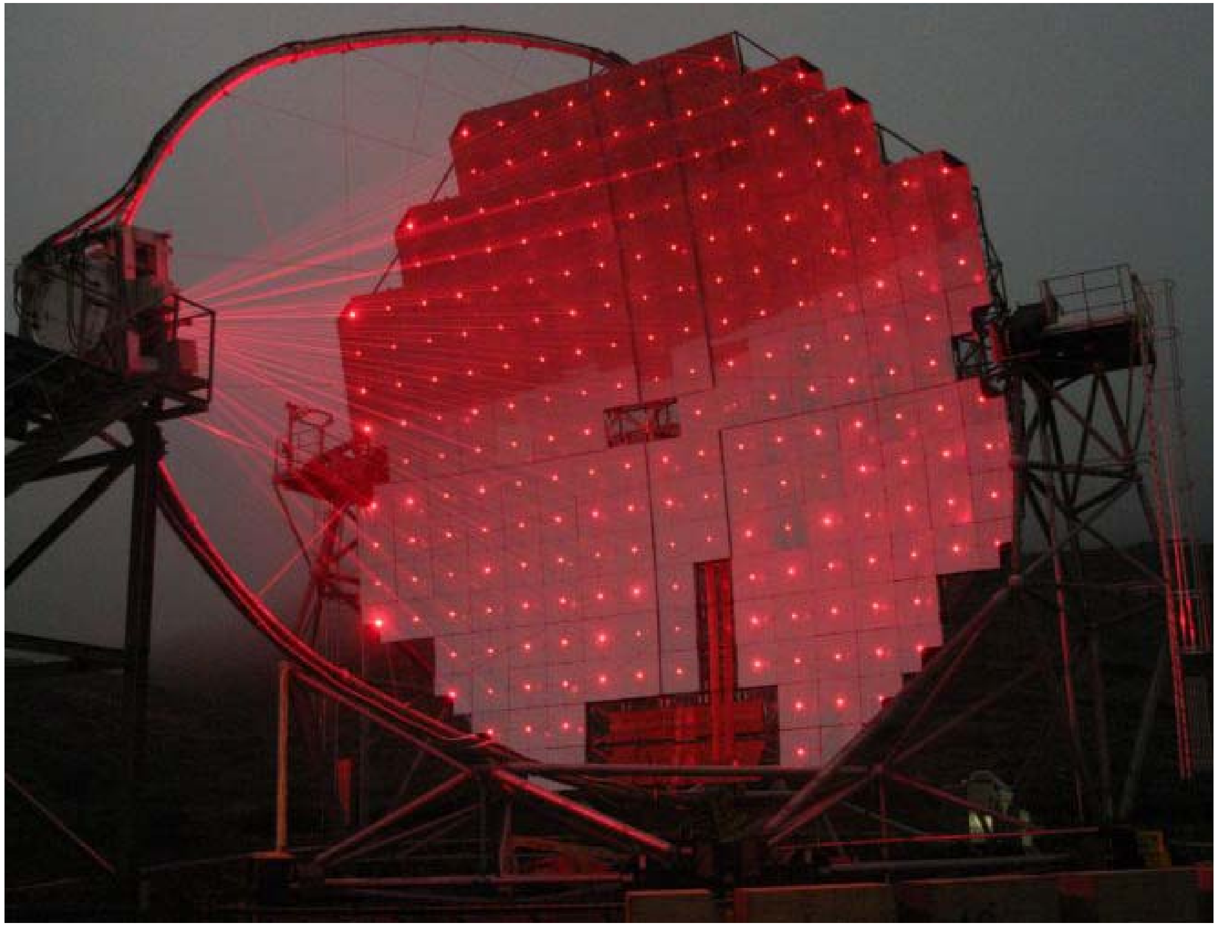
- Massive weight and cost savings over a rigid body telescope – the only practical way of building ELTs.

- Slow – 1Hz or less

Active Optics Sensing

- Live sensing from starlight
- Live sensing from a calibration source
- Pre-generated look-up table of distortion vs. pointing angle, temperature etc
- Critical for segmented mirror telescopes

Active Optics



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Active Optics

Adaptive Optics

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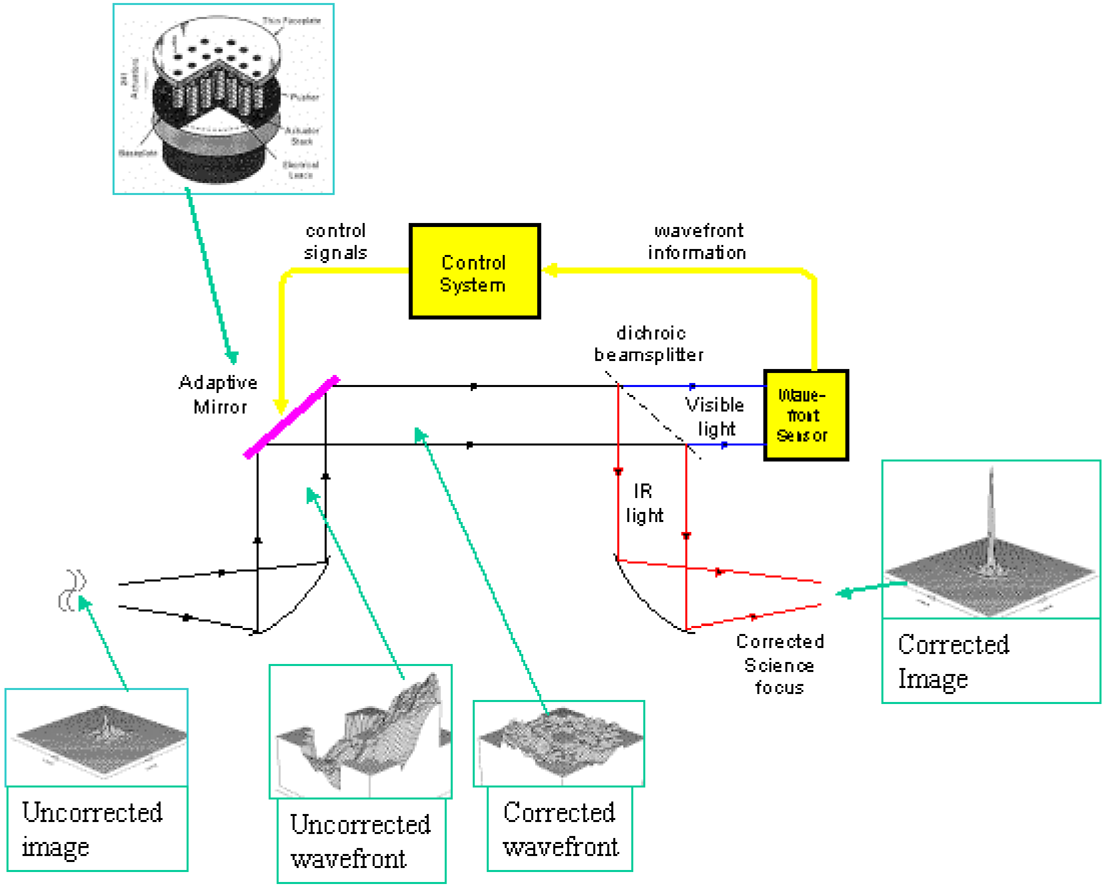
Adaptive Optics

An AO system measures dynamic turbulence with a **wavefront sensor** and corrects it with a **deformable mirror** or **spatial light modulator**



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Applications of AO

- Astronomy
  - AO is fully integral to current VLTs and future ELTs
- Ophthalmology
  - Retinal imaging, measuring distortions
- High power lasers
  - Intra-cavity wavefront shaping. e.g. Vulcan fusion laser (ICF)
- Optical drive pickups
- Microscopy
- Free space optical communication
- Military

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Wavefront sensors

- There are many types of wavefront sensors
- Shack Hartmann, Curvature, Pyramid, Point Diffraction Interferometer, Lateral Shearing Interferometer, ………..
- A wavefront sensor can be used for metrology as well as AO
- Today I'm going to focus on the Shack-Hartmann,
- This is a common sensor with perhaps the most similarity to position sensing

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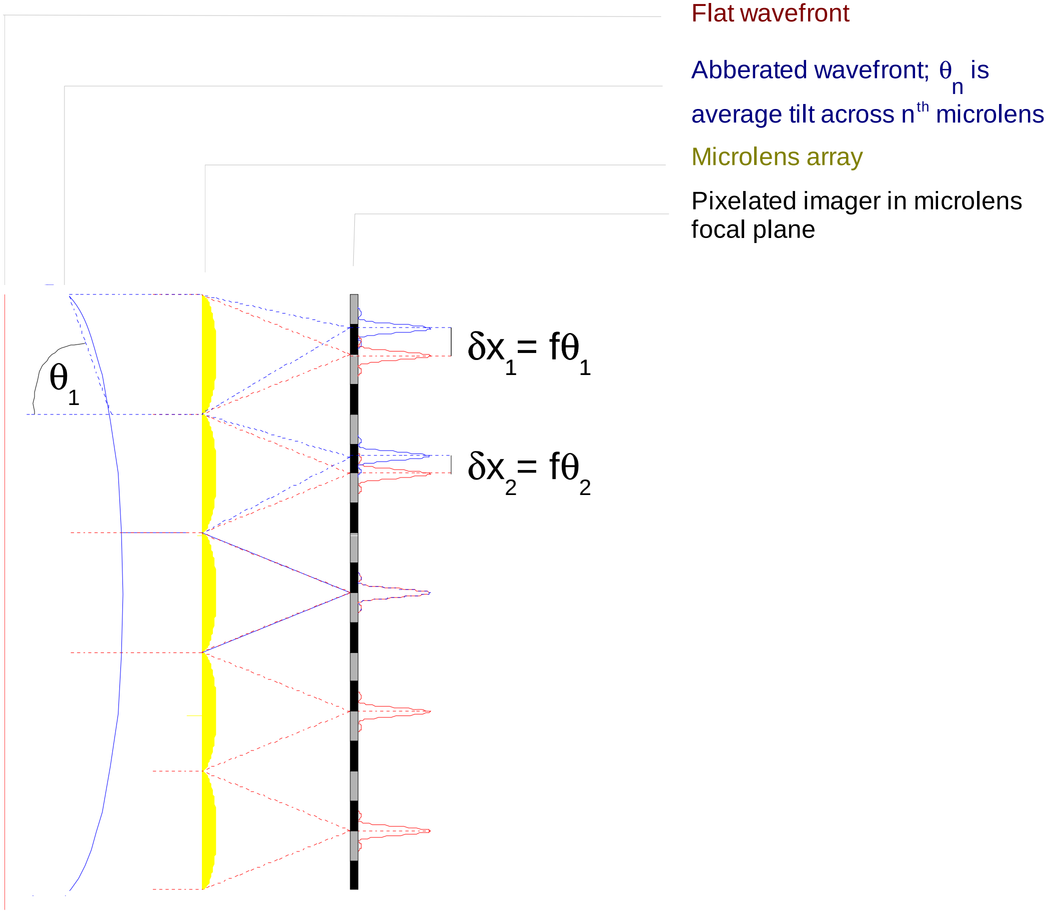
The Shack Hartmann Sensor



An array of small lenses (200um typical) segments a wavefront into sub-apertures and focuses these to a spot array

Spot displacement is related to local wavefront tilt

These are measured by an image sensor and reconstructed into wavefronts

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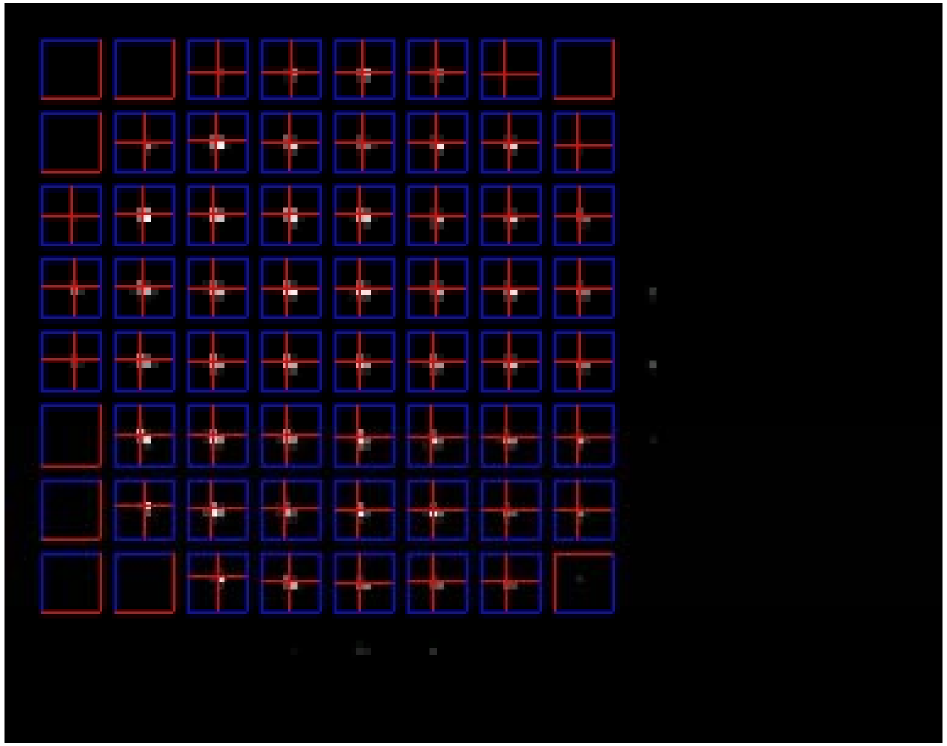
Example movie of an SH



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Astronomical sensing - requirements

- Low light levels – stars are very faint!
  - Every photon counts
  - Want high Q.E., low read noise
- Typical sensing rates of 1,000Hz
- Many spots to sense – 1000's of spots per sensor and many sensors for next generation instruments
- The CCD is king
  - Multi-port (minimise readout times)
  - Frame transfer (maximise exposure times)
  - Peltier cooled – low noise
  - On chip charge amplification – e.g. E2V L3 devices

Data overload!

- Using a pixelated image sensor to measure the position of the SH spots generates a lot of data
- As astronomical systems increase in size this gets worse
- Moving this data around starts to cost more than acquiring it!
- We don’t actually care about the images, just the positions
- Let’s get smart

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Smart sensing – future directions…

- Integrate position sensing with a pixelated detector
- The speed and operational simplicity off a quadcell
- The flexibility of an image sensor – variable geometry, rapid setup etc
- Several approaches

1. Custom CMOS sensor with pixel array(s) and processing electronics
2. Hybrid CCD/CMOS device
3. Smart camera

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Custom CMOS sensor with logic

- School of Electrical and Electronic Engineering & School of Optical Engineering, University of Nottingham
- Prototype APS and position measuring logic on one chip
- A final device would have a 2D grid of these cells
- Could enable the use of lock-in techniques for use in optically noisy environments

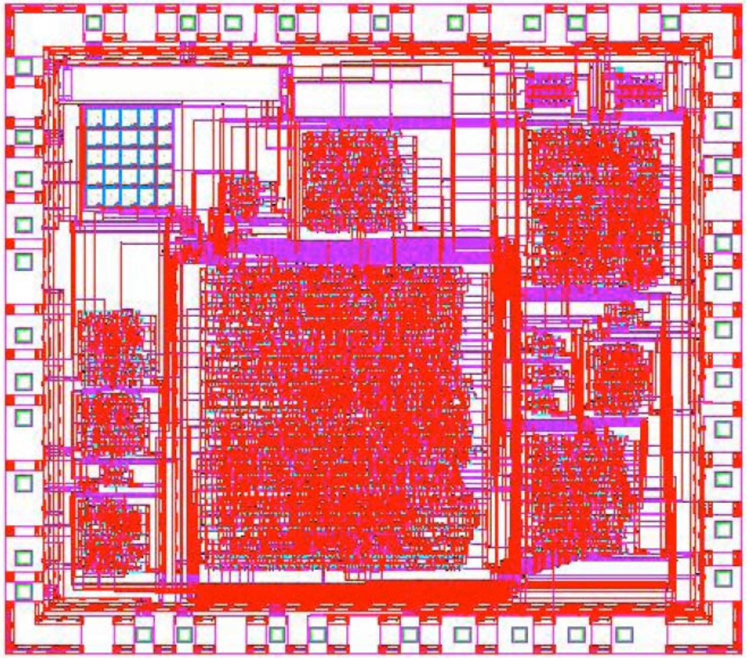

Image credit: University of Notthingham

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Hybrid CCD/CMOS sensor

- CCD has best optical properties
- CMOS can implement amplifiers, ADCs, processing
- Join a CCD sensing wafer to a CMOS processing wafer
- 'Bump bonding' – similar to flip-chip BGA packaging
- Can have massively parallel readout from CCD to CMOS
- Fairchild, Princeton Instruments, E2V etc…

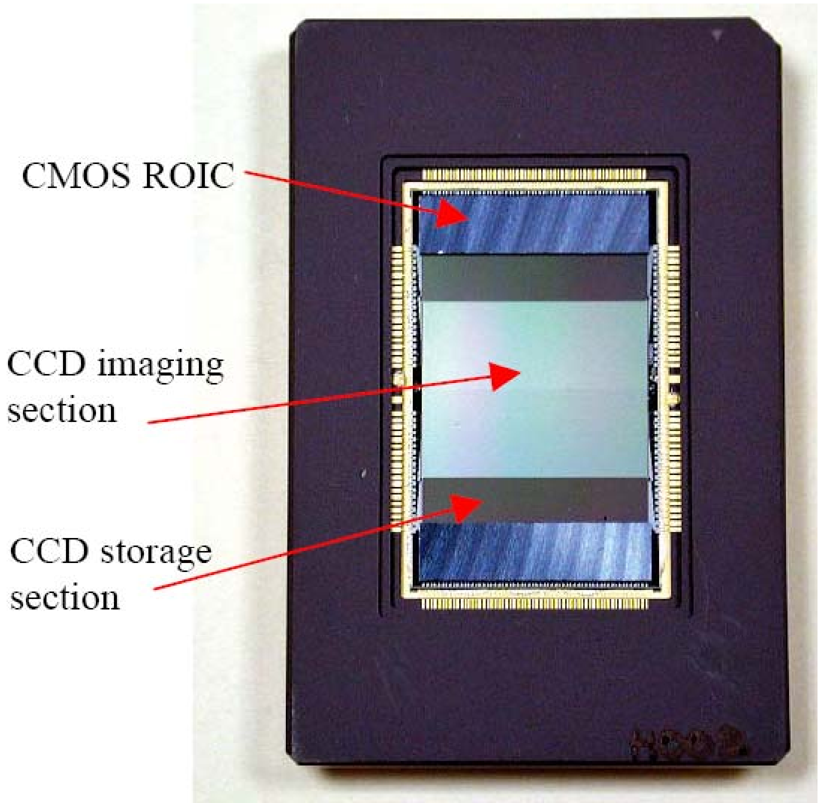

Image credit: Fairchild Imaging, Inc.

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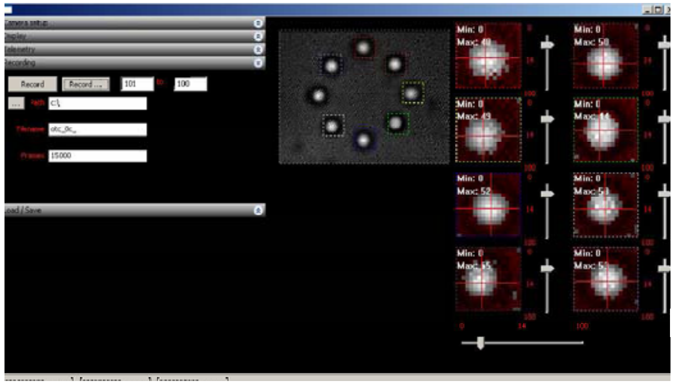
Smart Camera

- We built a smart camera at Durham for AO
- 640 x 480 pixel CMOS sensor, 80MHz pixel clock
- Integrates SH processing and AO control
- FPGA based
- We have found other applications for this such as position sensing in optical tweezers
- 160MB/sec of pixel data is processed by the camera into < 2MB/sec of position data and video rate images for setup
- Exploiting this through our spinout - DSI



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What if…

- Bump bonding custom ASICs to CCDs is expensive – lots of NRE per application/ASIC
- How about using a programmable device instead of an ASIC – either an FPGA or a DSP
- FPGA is reprogrammed for different applications – particle event detection, centroiding, motion detection, compression…
- Would require the development of a new FPGA with analogue front end for ADCs and clocking
- FPGA would generate readout clocks, downsample data etc.
- Modern FPGAs can interface to 3Gb/sec to 10GB/sec serial interface
- ‘Field programmable optical array’

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The End

Thanks for listening

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