The MROI fast tip-tilt correction and target acquisition system

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Outline

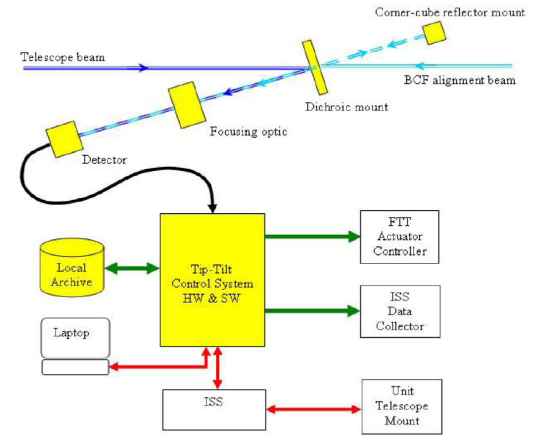
System Role

- One system per UT, mounted on Nasmyth optical table
- Uses “visible” light 350–1000 nm; other colours sent to beam-combining laboratory
- Fast tip-tilt correction using UT actuated secondary mirror
  - Tip-tilt zero point on FTT camera defined at start of night as part of interferometer automated alignment
- Narrow-field $(60'')$ target acquisition
- Integrated with MROI supervisory control system

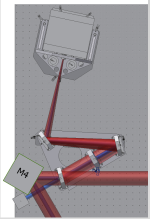
Key Requirements

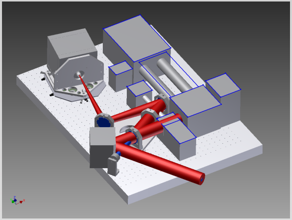
- Acquisition and fast tip-tilt correction modes
- **Limiting sensitivity** $\geq 16^{\text{th}}$ magnitude
- **Zero-point stability** $\leq 0.060''$ on sky for $\Delta T = 5\ {}^\circ\mathrm{C}$
- $T - T_{\text{ambient}} \leq 2\ {}^\circ\mathrm{C}$ for components on Nasmyth optical table; power consumption < 250 W
- Time-varying objective point for dispersion compensation and/or off-axis reference star
- Continuous streaming of diagnostic data to ISS

Design Overview



Optical design and layout

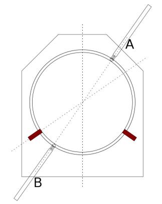




- Transmissive design with custom cemented triplet lens
  - Angular stability tolerance 20× that for OAP mirror
  - Temperature-dependent focal length compensates for expansion of steel table top

Opto-mechanical design (i)

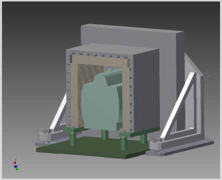
- Monolithic, symmetric mounts
- “Material compensation” to keep lens centred in its mount
- Construct mounts from Aluminium alloy to minimize thermal equilibration time
    - Costs of invar not justified, worse thermal conductivity almost cancels lower CTE

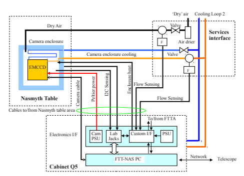


Opto-mechanical design (ii)

- Common baseplate to mitigate effects of Nasmyth table deformations
- Separate camera mount to avoid transmitting heat and vibration to optics
- Baseplate and camera mount have kinematic interfaces to Nasmyth table to accommodate differential expansion

Thermal design



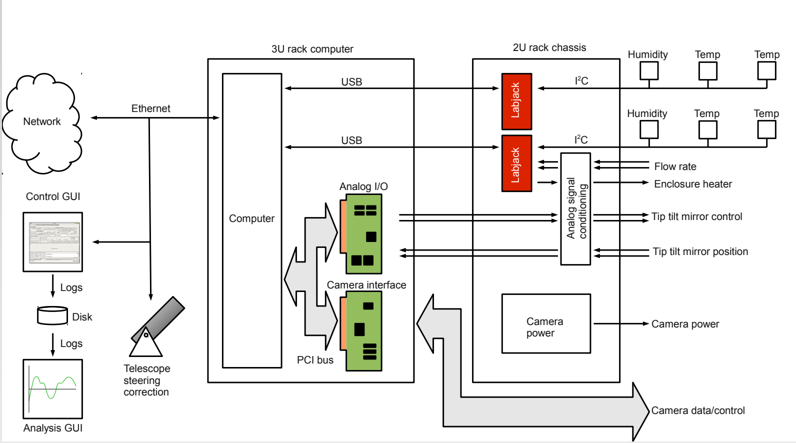


- Camera thermal enclosure:
  - Maintains camera above 0 °C and non-condensing, surface temperature within 2 °C of ambient
  - Uses convenient electronics cabinet cooling loop
  - Mechanically isolated from camera mount

Electronics design

- In UT enclosure electronics cabinet:
  - Rack-mount PC
    - Andor camera interface PCI card
    - Analogue/digital to fast tip-tilt mirror controller
  - EMCCD Peltier power supply
  - 2× USB Labjack analogue/digital I/O
    - Each includes I^2C bus to temperature and humidity sensors
  - Custom interface circuit board
  - Power supply

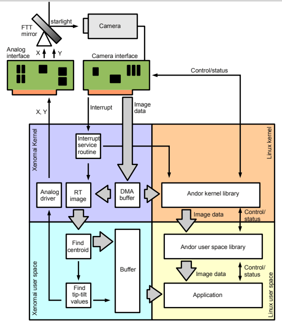
Software execution environment



Software components

- **Environment controller** Thermal control/monitoring of camera enclosure
- **System controller** Hard real-time fast tip-tilt loop closure, target acquisition
- **Control/display GUI** Live image/monitor data display, data recording
- **Analysis GUI** Data visualization and analysis

System controller real-time architecture

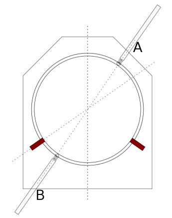


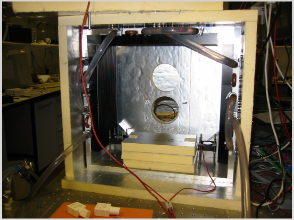
- Based on Xenomai — kernel-space and user-space hard real-time contexts that coexist with Linux
- Open-source Andor driver modified to provide parallel real-time access to pixel data
- Uses floating point in user-space real-time context

Camera readout testing

- We have measured frame rate, latency, noise for preliminary 23 $\times$ 23 pixel custom readout mode
- Andor are developing a 32 $\times$ 32 pixel version
  - Larger FoV to accommodate field rotation when using off-axis reference object
  - Andor report $1\ \mathrm{kHz}$ frame rate and $\sim 1\ \mathrm{ms}$ latency
  - Latency is consistent with our model for the readout timing
- We have measured total interrupt and compute latency as insignificant $38\ \mu\mathrm{s}$

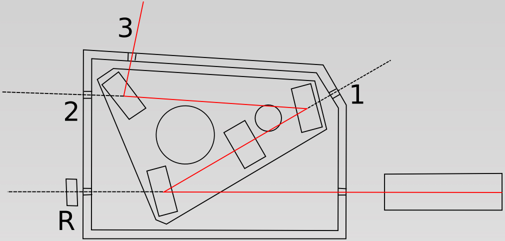
Individual component testing

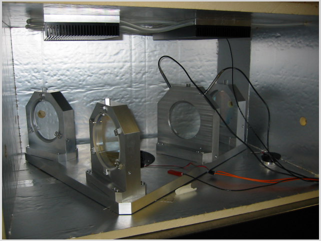




Element	Degree of freedom	Measured motion	Required stability
Dichroic/mirror mount	Piston stability	100 nm	$<$ 500 nm
Dichroic/mirror mount	Tilt stability	$\leq$ 100 nm	45 nm
Lens mount	Shear stability	$\leq$ 250 nm	$\sim$ 350 nm

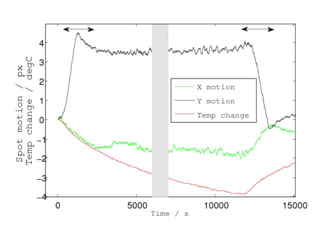
Integrated testing

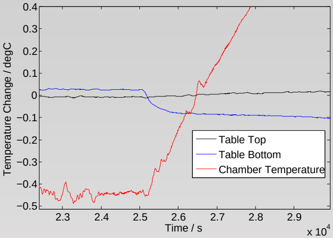




- R is reference beam port
- 1 & 2 are intermediate test ports
- 3 is output port to FTT camera

Integrated test results





- Large excursions when ΔT between optical table top and bottom skins changes rapidly
- At other times, for several-degree temperature changes, motion is $\sim 2\times$ requirement

Conclusions

- Prototypes of critical system components have been built and tested
- Laboratory test results validate design approach
  - Optomechanical stability within (at least) factor 2 of demanding requirements already demonstrated
  - Preliminary test results predict 43 Hz closed loop bandwidth
- Final design and fabrication of first system underway
- Preliminary version of real-time control software complete and working