Master's Thesis Engineering Technology

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FPGA-based Active Pointing Correction of Optical Instruments on Small Satellites

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CubeSats

- Mini-satellite standard
- 1U = 10x10x10 cm
- Mass ~1 kg

CubeSats offer:

- On-orbit testing of scientific experiments
- Wide spectrum of applications across the scientific community
- Made space more accessible
- Educational activities and programmes

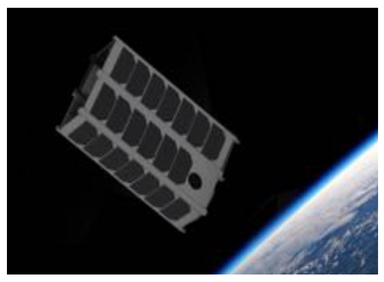


Figure 1. *6U CubeSat in orbit*

CUBESPEC

- 6U CubeSat mission concept
- Telescope consisting of a primary mirror (M1) and a secondary mirror (M2)
- Scientific payload consists of a spectrograph that requires high angular pointing accuracy of **3.6 arcseconds**

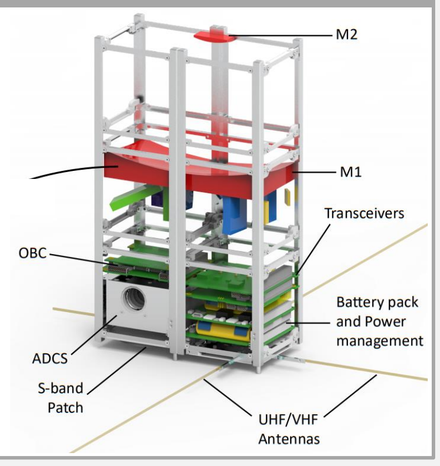


Figure 2. *CUBESPEC configuration (Raskin et al.)*

Problem Statement

- Attitude Determination and Control System (ADCS) provides coarse pointing of the satellite
- Target stars drift on the image sensor due to lack of high-precising pointing
- Expected ADCS drift **~100 arcseconds**

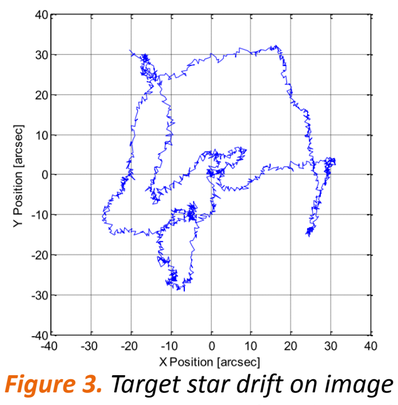


Figure 3. *Target star drift on image sensor (Smith et al.)*

Solution

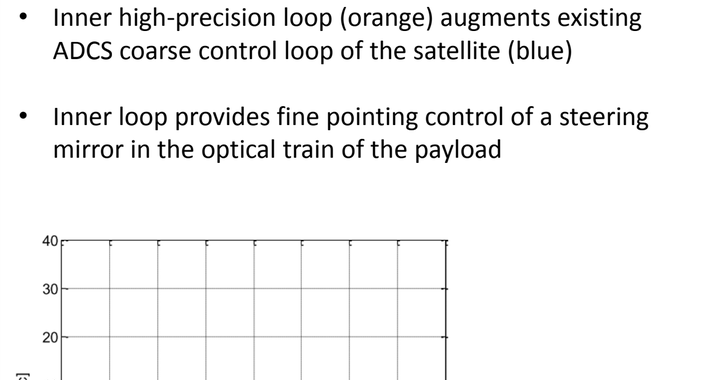


Figure 4. *Control loop diagram*

- Inner high-precision loop (orange) augments existing ADCS coarse control loop of the satellite (blue)
- Inner loop provides fine pointing control of a steering mirror in the optical train of the payload

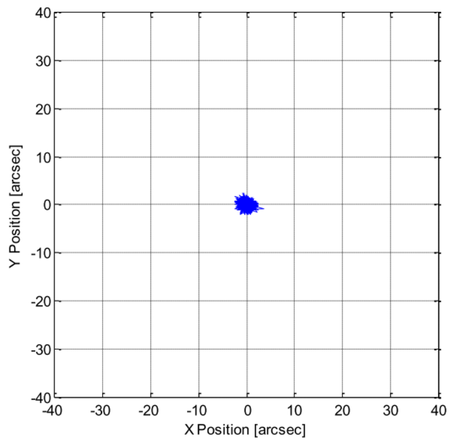


Figure 5. *Star movement on detector with active correction enabled (Smith et al.)*

Fine Guidance Sensor (FGS)

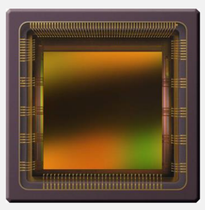
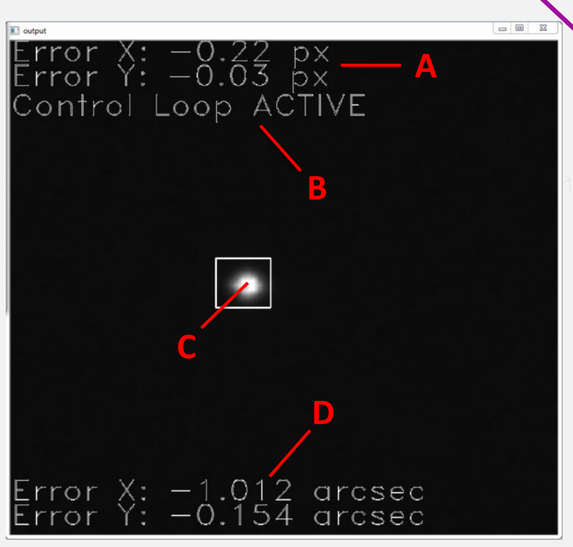
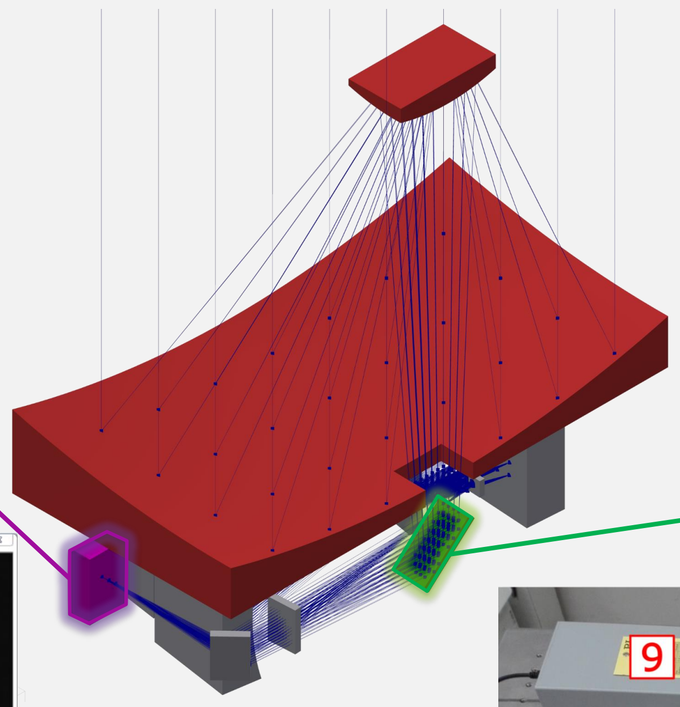


Figure 6. *CMV4000 CMOS image sensor*

- Used as optical feedback element
- Detects deviation of the target star
- Platescale in test-setup: **4.5 arcsec/pix**



A. **Control error in pixels**
B. **Loop status**
C. **Target star and control setpoint**
D. **Control error in arcseconds**



1. **Laser**
2. **Collimator and lens**
3. **Fine Steering Mirror (FSM)**
4. **Fine Guidance Sensor (FGS)**
5. **Piezo amplifier**
6. **Digital-to-analog converters**
7. **Zynq-7000 FPGA**
8. **Translating piezo**
9. **E-861 LPS24 Controller**

Left: *Control-loop interface*
Right: *Test-setup on the optical bench*
Top: *CUBESPEC pointing platform (Raskin et al.)*

Fine Steering Mirror (FSM)

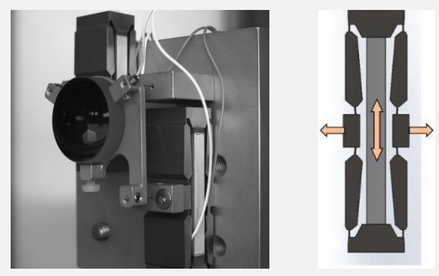
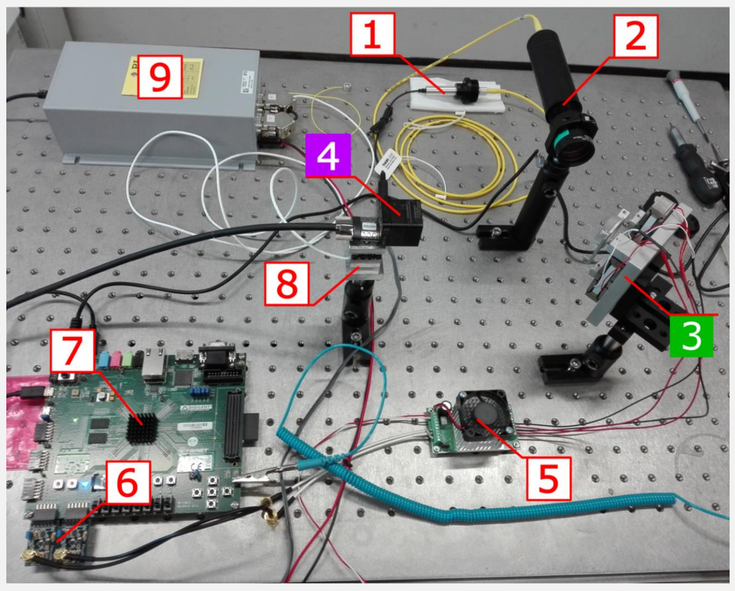
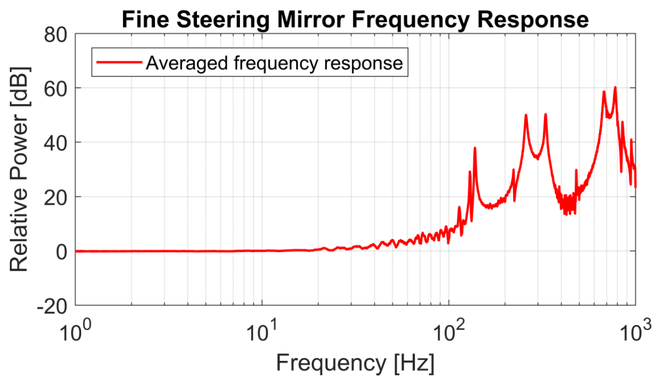


Figure 7. *Steering mirror and actuator*

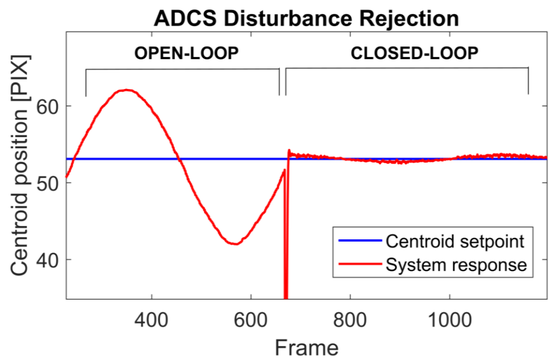
- Tip-tilt steering mirror
- Amplified stack piezoelectric actuators



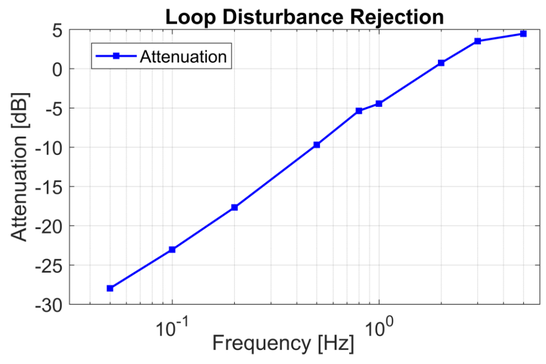
Results



- Indicates steering mirror control bandwidth
- Bandwidth: 0 – 45 Hz (+3 dB)
- First eigenfrequency above 100 Hz



- ADCS disturbance of 100 arcsec (22 pix p-p) and f = 0.05 Hz introduced via translating piezo **(8)**
- Loop samplerate: 30 Hz
- Resulting error: within -1.8 and +1.8 arcseconds for 82% of the time, meeting the requirement



- Disturbances with lower frequencies experience a higher attenuation
- Steady state errors are eliminated since DC attenuation is infinite

Conclusion

- Universal testbed for active pointing correction on small satellites
- Live monitoring and control parameter adjustment
- Measurement of step/frequency response
- Analysis of control loop disturbance rejection
- With the current control loop parameters: CUBESPEC pointing requirement is met if main frequency component in ADCS drift is less than 0.05 Hz

G. Raskin *et al.*, "CUBESPEC : Low-cost astronomical spectroscopy from a nano-satellite," *SPIE*, 2018.

M. W. Smith *et al.*, "The ExoplanetSat Mission to Detect Transiting Exoplanets with a CubeSat Space Telescope," *Proc. 25th Annu. Small Satell. Conf.*, pp. 1–9, 2011.

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