Precision Pointing for the Wide-Field Infrared Survey Telescope (WFIRST)

Eric Stoneking
Oscar Hsu
Gary Welter
Outline

• Introduction to WFIRST
• Fine Guidance Sensor
• Slew Laws
• Wheel Nullspace Control Law
• GNC Hardware Architecture
• Conclusion
Introduction to WFIRST

• Hubble-class Telescope
  – 2.4-m aperture
  – Jitter: 14 milliarsec RMS
  – Stability: 11.6 milliarcsec RMS over 180 sec exposures
  – Near infrared
    • Detectors ~100 Kelvin

• Science campaigns interleaved over 6-year mission
  – Supernova Survey: Cosmic Expansion
  – High Latitude Survey
    • Baryonic Acoustic Oscillation: Dark Energy
    • Weak Lensing Survey: Dark Matter
  – Microlensing Exoplanet Survey: Census
  – Exoplanet Coronagraphy: Characterization
Wide Field
432 Hubble Pointings...
Covered by 2 WFIRST Pointings

M31 PHAT Survey
432 Hubble WFC3/IR pointings
2 WFIRST pointings
Fine Guidance Sensor

- FGS is integral to Wide Field Instrument
  - One guide window per detector (18)
    - HAWAII-4RG 4Kx4K
  - GW data readout interleaved with science data readout
    - 0.17-sec GW sample time vs. 5-sec science frame
- Six waveband filters for imaging, plus a grism for spectroscopy
  - Filters affect perceived magnitude, PSF of guide stars
  - Grism spreads star image over ~800 pixels in one dimension
FGS Image Tracking

- Track up to 18 stars
  - One per detector
- Magnitude Range H(AB) 14.5 to 17
- Centroid computed using Discrete Fourier Transform (DFT)
  - Fit subwindow readings to sine, cosine
  - Phase angle yields centroid
  - Accurate, robust to noise
FGS Spectrum Tracking

- H(AB) 10 to 12
  - Limited by signal-to-noise
- 3-4 stars tracked
  - Limited by distribution on sky
- Fit pixel measurements to a curve
- 0.25-sec sample time
- Simulations show centroiding to 100 milliarcsec in dispersed direction
FGS Acquisition

- Survey operations require rapid slew and acquisition of FGS at each target
- During slew, attitude determination based on star trackers, gyros
- Handoff from ST-IRU to FGS guidance uses a dedicated Settle mode
  - Acquisition guide windows are larger (64x64 pixels) to envelope expected ST-based attitude errors
  - Each guide window searches for candidate guide stars to match uploaded pattern
  - FGS takes over pointing guidance once enough (~4) stars are tracked
    - All guide windows reduced to tracking size (16x16 pixels)
    - Any guide windows failing to match the pattern restart search using improved offsets
  - Once locked, guide windows move if needed to follow guide stars
    - Allows acquisition in parallel with settling of residual slew motion
Slew Law: Profile

- Shaped slew profiles are used to minimize excitation of structural modes
  - “Rise time” of 1-2 sec to avoid 1-Hz mode
- Most slews are torque-limited
  - Rate-limited above ~6.5 deg
WFIRST has a Field of Regard defined by a Sun Constraint
– Telescope boresight axis always kept between 54 deg and 126 deg from Sun
Eigenaxis Slew May Violate Sun Constraint

- Telescope Boresight trace in Red
  - Observatory +X Axis
- Sun is “pole” in this view
- Slew endpoints are within Field of Regard, but +X axis travels through Sun keep-out zone
• Euler Angle Sequence introduced, based on FoR
• Slew is monotonic in each Euler angle
  – If both endpoints are in FoR, then every point along slew is too
• All three ‘single-axis’ slews performed concurrently
  – Two shorter slews scaled in time to match longest slew duration
Wheel Nullspace Control

• Four wheels provide three axes of control, plus one null-torque degree of freedom

• This DOF is used for:
  – 1) Balance the work to avoid spinning one wheel up more than its share
    • Conserves torque authority, prolongs interval between momentum unloads
  – 2) Keep wheel speeds separated by 1 Hz
    • Avoids reinforcing undesirable excitation of structural resonances
  – 3) Push each wheel through its zero-speed crossing
    • Minimizes perturbation to pointing stability

• It can’t all be done at once with only one DOF, but:
  – Balance, separation are naturally opposed to each other
  – Zero-speed crossings are episodic
  – So a weighted multi-term control law finds a happy medium
Wheel Momenta

- Initial speed separation must be done by targeted momentum unload
  - Some wheel speed crossings are unavoidable, but not long-term
- Solar radiation pressure causes steady ramp
- As each wheel approaches zero, it is pushed through
  - This perturbs other wheel speeds
  - Zero-crossings spaced so only one wheel is involved at a time

Wheel Momenta in Absolute Value Over a Day

![Graph showing wheel momenta over time.](image)
GNC Hardware Architecture

- GNC architecture is single-fault tolerant
- Sensors:
  - Coarse sun sensors (4-pi steradian coverage)
  - Inertial Reference Unit
    - Angle random walk is performance driver for larger slews
  - Star sensors (3)
  - Fine Guidance Sensor (integral with Wide-Field Instrument)
- Actuators
  - Reaction Wheels (now considering 6x)
  - Thrusters
    - 8x 22-N class for insertion, midcourse maneuvers
    - 16x 5-N class for stationkeeping, momentum unload
Conclusion

• WFIRST is a unique combination of precision pointing and agility
  – FGS integral with Wide-Field Instrument
  – Rapid and robust handoff from star tracker-gyro to FGS
  – Avoid structural excitation
    • Shaped slews
    • Wheel nullspace management

• Hardware architecture definition is in work
  – Currently in Phase A, requirements definition
    • Components have not been selected
    • Basic architecture and requirements are outlined
  – Late-breaking: Moving to 6-wheel architecture from 4 wheels
    • Need high torque for microlensing slews