Celestial Attitude Reference and Determination System (CARDS) Daytime Star Tracker

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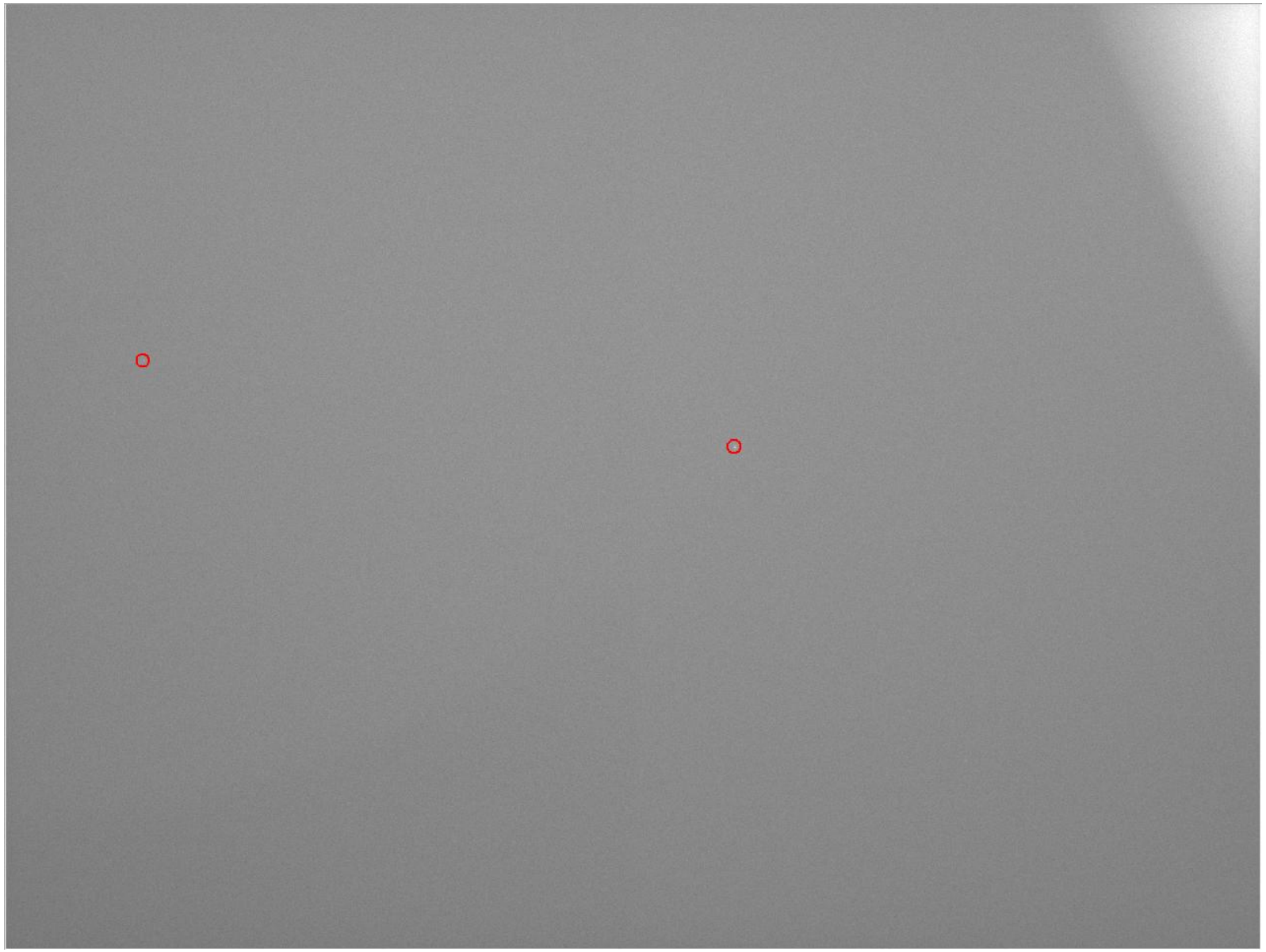
Introduction

- CARDS is a system allowing for modular integration of multiple sensor types with custom algorithms and multiple I/O interfaces
  - Can connect multiple cameras for different functions and output on different interfaces to multiple “users”
  - Configurable via XML script
- Grew out of work on GigE cameras for attitude sensors
- Sun sensor and single star tracker developed to support WASP
  - Flew sun sensor and daytime bright body tracker on HYSICS2 (Aug, 2014)
  - Flew daytime bright body tracker on OPIS (Oct, 2014)
    - Became pathfinder for daytime star tracker

Pathfinder Daytime Star Tracker

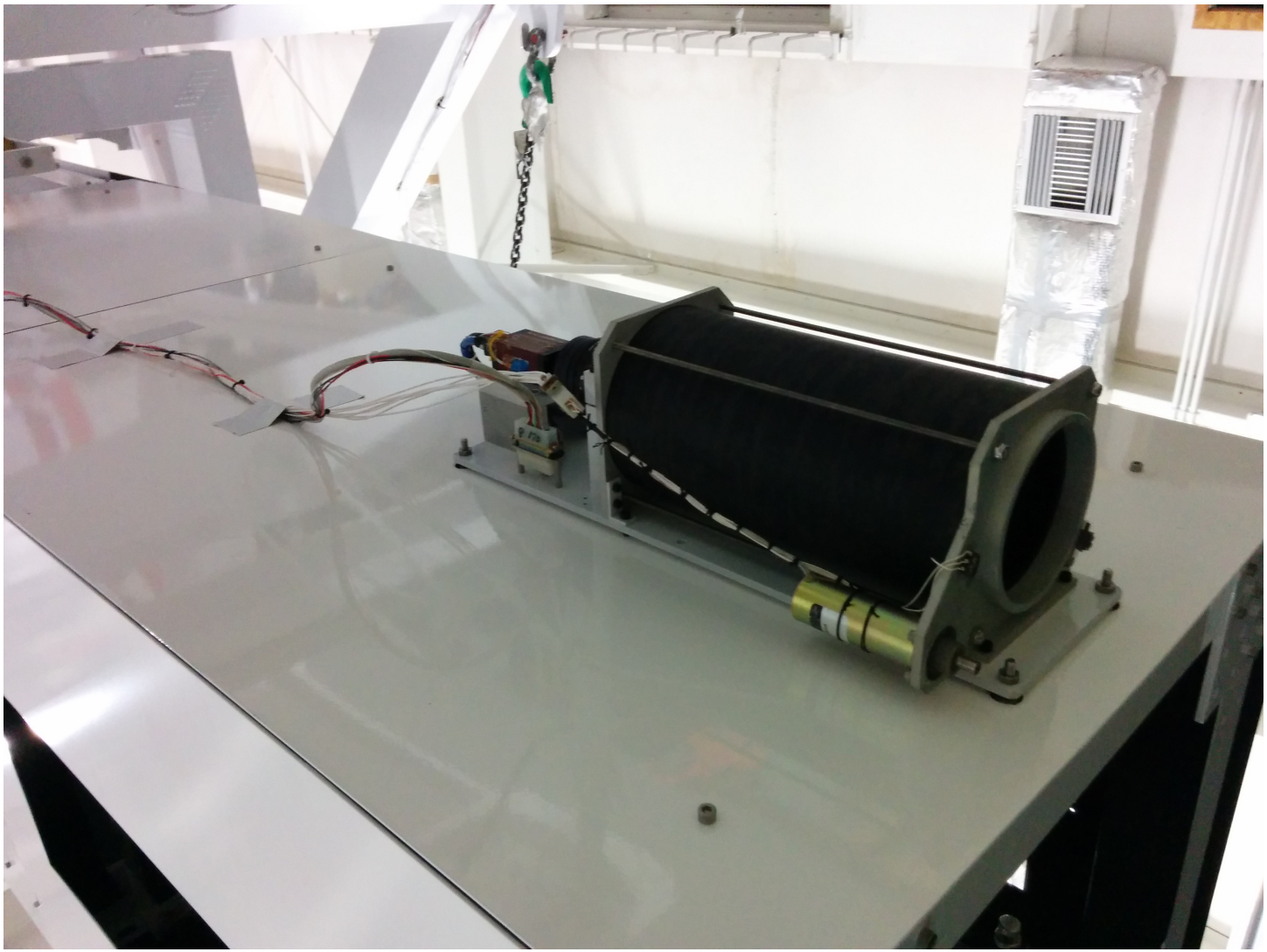
- Followed in footsteps of previous missions BLAST and HERO, as well as, DayStar development
  - CCD with longpass filter at edge of visible region
- All COTS
  - Technologic 1GHz Arm embedded computer running Linux
  - GigE Allied Vision Tech Manta G-283
    - Sony ICX674 CCD
  - Zeiss 85mm f/1.4 lens with IR coatings
  - Lumicon Hydrogen-Alpha Filter (650nm longpass)
- Flight on OPIS
  - Single star tracking of bright bodies during daytime and storing images for post processing
    - Stored images shows stars down to $\sim$4.5 magnitude
  - 105kft altitude limited seeing dimmer stars
  - Method for setting focus of the lens was crude and has since been refined

Image of Alphekka from OPIS flight



Red circles are at stars.

Pathfinder Daytime Star Tracker

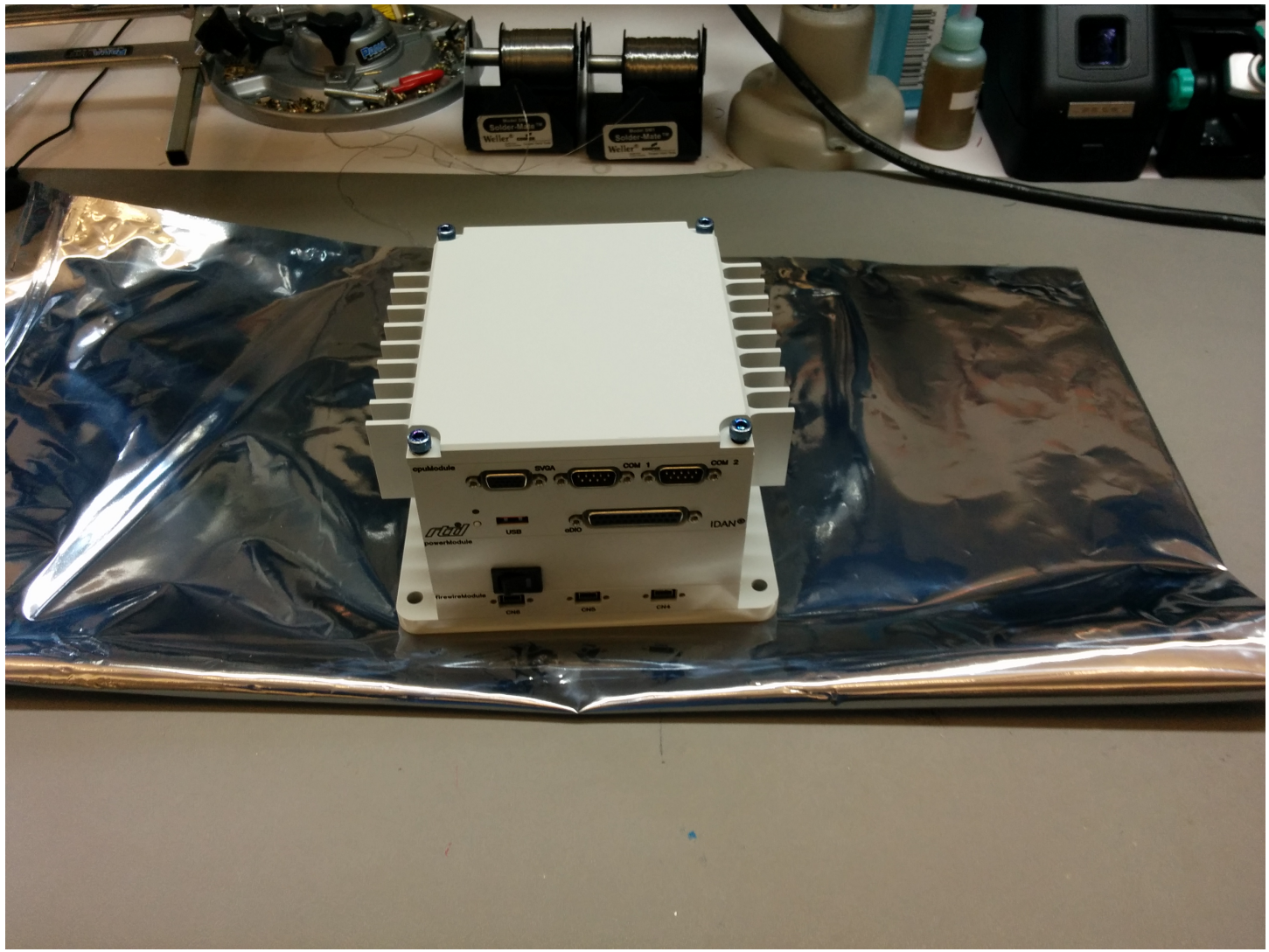


Daytime Star Tracker Design

- Switched from Allied Vision Tech camera to Point Grey GX-FW-28S5M-C
  - GigE to Firewire camera interface
  - Firewire allows for DMA image transfer
  - greatly reduces CPU load
  - same Sony ICX674 sensor
- Switched to RTD with 1Ghz AMD Fusion processor
  - RTD has Firewire modules
  - Increased power and weight
- Kept Zeiss Lens and Filter
- Voltage = 8-36V
- TLM = RS-422, RS-232, UDP
- Power = 18W
- Mass
  - Tracker Head = 1.6 kg
  - RTD Computer = 2.4 kg

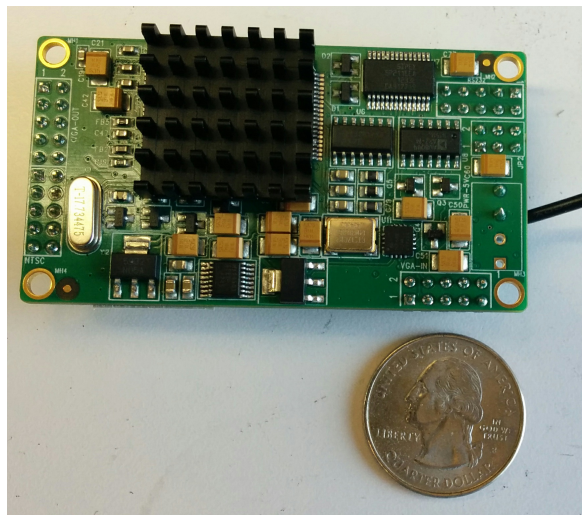
Daytime Star Tracker Head

Daytime Star Tracker Processor



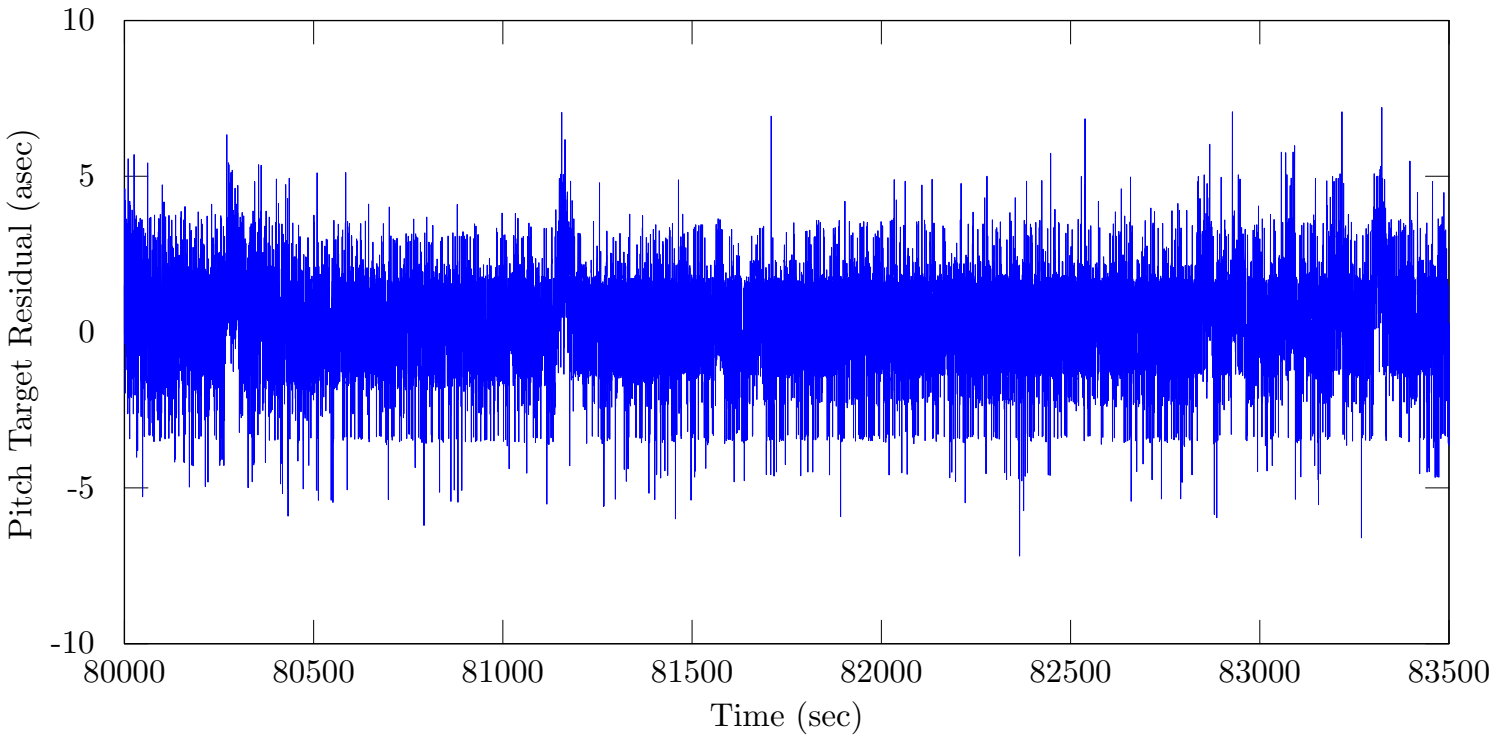
Daytime Star Tracker Design Cont.

- Video Downlink
  - Gives situational awareness of what the tracker is pointed at
  - Advanced Micro Peripherals NanoVTV
    - Converts non-interlaced VGA signals to NTSC/PAL signals
    - +5 VDC
    - 2.75” x 1.75” form factor
  - Writing 2x2 binned image to frame buffer which is piped to NanoVTV
  - NTSC signal sent to SIP which sends to ground via TV transmitter



Daytime Star Tracker Performance

- FOV = 5.9°x 4.4°
- Noise Equivalent Angle (NEA)
  - Perpendicular to Boresight ≈ 5 asec 3-σ
  - From OPIS pathfinder data (single star)



Modes

- Idle
  - Sit and wait for ground commands
- Lost In Space
  - Solves for attitude based on star pattern
- Tracking
  - Attitude based on tracking stars
  - Search for new stars as stars enter and leave FOV
- Bright Spots
  - Contingency mode
  - Ground commands used to id spots in image
  - Allows for jump starting tracking if LIS fails due to a lack of stars during daytime

Algorithms

- Star detection
  - Novel convolution scheme with standard blob detection algorithm to find stars in strong background gradient
- Star Centroiding
  - Simple center of intensity calculation for sub pixel accuracy
- Lost In Space
  - Using Pyramid algorithm with k-vector search*
- Tracking
  - Nearest neighbor search for finding new stars
- Quaternion estimation
  - ESOQ-2†

Mortari, D., Samann, M. The Pyramid Star Identification Technique.

†*Mortari, D.* ESOQ-2 Single-Point Algorithm for Fast Optimal Spacecraft Attitude Determination.

Current/Future work

- WASP Flights
  - X-Calibur (Fall 2016 Fort Sumner and Winter 2018 Antarctica)
  - PICTURE-C (Fall 2017 Fort Sumner, Fall 2019 Fort Sumner)
    - PICTURE-C science doesn't need daytime pointing but day time can be used for extra testing of daytime star tracker before mission begins
- Transition to new lens
  - Zeiss discontinued IR version of lens
    - Only have three flight lens
  - Working with Sting Ray Optics to a near COTS replacement
    - 100mm f/1.5 SWIR lens