Development of the Fabry-Perot Spectrometer Application

Kathryn Browne
Code 587
Overview

• Fabry-Perot Spectrometer (FPS)
• Conclusion
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SpaceCube

- Radiation hardened flight processors can be one to two generations behind
- Science data does not need to be perfect all the time especially if you can collect and process more data using newer technology
- Uses processors that are not radiation hardened and can recover from radiation induced upsets when they occur
- Is a high performance reconfigurable science data processor based on Xilinx Virtex FPGAs
  - Hybrid processing – CPU, DSP, and FPGA logic
  - Integrated “radiation upset mitigation” techniques
  - Critical function watchdogs
International Space Station
SpaceCube Experiment Mini

- **SpaceCube Mini (Virtex 5 FPGA)**
  - Demonstrate performance
  - Earth Science on-board processing algorithm development
  - Demonstrate 300 to 1 data reduction

- **Fabry-Perot Spectrometer (FPS)**
  - Demonstrate a smaller and cheaper way to measure methane in the atmosphere
  - Measure absorption by atmospheric gases in sunlight reflected off the Earth
  - Demonstrate measurements of atmospheric methane from space

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- **Electro Hydro-Dynamic (EHD) Thermal Experiment**
  - EHD pumping of liquids in embedded micro-channels using electrical fields
  - Provide advanced thermal control for “power dense” electronics systems

- **CHREC Space Processor**
  - Demonstrate next generation processor
Space Test Program – Houston 5

• Next DoD STP external ISS payload
  • Build upon successes of MISSE 6/7/8, STP-H3, and STP-H4

• Launch June 2016 on SpaceX Commercial Resupply Service 10 (SpX-10)

• Operate 2 years on ISS Express Logistics Carrier 1 (ELC)

• STP – H5 Includes 14 experiments
  • ISS SpaceCube Experiment – Mini (ISEM) (NASA GSFC)
    • Electric Hydro-Dynamic
    • Fabry-Perot (Upper Atmosphere) Spectrometer for Methane
    • SSCO Raven (Vis, IR, Flash Lidar, Gimbal) (Satellite Servicing Capabilities Office)
    • Innovative Coatings Experiment (Materials Exposure, req’s crew imagery)
    • CSP – CHREC Space Processor (Demo next gen processor)
Location

Zenith

Nadir

ISS Flying Towards You

STP-H5
ELC 1
Importance of the Fabry-Perot Spectrometer for Measuring Methane

• Methane’s global warming effects are 20 times worse than that of carbon dioxide
• Measuring methane from melting permafrost and methane hydrates can help with global warming calculations
• There is currently an aircraft mission to measure methane being released from the permafrost but it can’t provide continuous monitoring
• No plans to develop instruments that monitor methane over the next 10 years
How?
FPS Box

Mirror

FP Camera

Camera Link Connector which connects to the SpaceCube Mini

CSP Camera

FP

Mirror

Band Pass Filter

Telescope
FPS

METHANE ABSORPTION LINES WITH FABRY–PEROT AND FILTER OVERLAY

H₂O  CO₂  CO₂  CO₂

FP #1

FP #2

WAVELENGTH

1642.0  1642.5  1643.0  1643.5  1644.0

1.0  0.8  0.6  0.4  0.2  0.0

1637.6 NM  1637.8 NM  1638.0 NM
Spectrum

- Ring 1: 2291
- Ring 2: 2232
- Ring 39: 1248
- Ring 40: 1240
Ring Percentages

- **Pixel 1:**
  - Location: 0, 0
  - Ring #: 1
  - Percent 1: 79
  - Percent 2: 21
  - Percent 3: 0

- **Pixel 2:**
  - Location: 0, 1
  - Ring #: 2
  - Percent 1: 91
  - Percent 2: 9
  - Percent 3: 0
Core Flight Executive (cFE)

• A set of *mission independent, re-usable, core* flight software services and operating environment
  • Provides standardized Application Programmer Interfaces (API)
  • Supports and hosts flight software applications (CFS Apps)
  • Applications can be added and removed at run-time (eases system integration and FSW maintenance)
  • Supports software development for on-board FSW, desktop FSW development and simulators
  • Supports a variety of hardware platform
  • Contains platform and mission configuration parameters that are used to tailor the cFE for a specific platform and mission

• Provides:
  • Executive services
  • Software bus services
  • Event services
  • Time services
  • Table services
  • File services
ISEM Software

CFE Core Apps
File Manager
Health & Safety
Scheduler
Housekeeping
Aeroflex Controller

CFE Software Bus

Stored Commands
Spectrometer App
Command Ingest
Telemetry Manager
FTDP
NRL Interface App

CFE Core Apps
File Manager
Health & Safety
FTDP

CSP App

Software Bus Network
FPS App Development Schedule

• Release 0 – 12/1/2014
  • Interfacing with the camera
  • Science algorithms
  • Sending data down

• Release 1 – 1/30/2015
  • Commanding

• Release 2 – 3/27/2015
  • Wish list features
Development Platform

- Image processing code was prototyped using Java and OpenCV
- FPS Application code written in C
- ML510 board
- SpaceCube Linux
FPS Application

• 3 operation modes
  • Silent Mode
  • Image Mode
  • Science Mode

• Algorithms
  • Find Circle
  • Calculate Ring Percentages
  • Calculate Average Background Intensity (Spectrum Correction)
  • Calculate Spectrum
Commanding

• Change Number of Averaged Spectrums
• Change Execution Mode
• Find Circle
• Change Average Background Location
• Change Time Between Averaging Background
• Change Image Send Rate
• Change Time Between Frame Captures
• Change Time Between Image HRT Packets
• Change Dead Pixel Mode
• Load New Dead Pixel Locations
• IR Camera Pass-Through Commands
• Set Center and Radius
• Load New Lookup Table
FPS Startup

• Startup in silent mode
• Initialize counters
• Read certain variables from flash

Ring Percentages Table File
• Radius
• Center x, y location
• Number of pixels
• Table entries
  • Pixel location in image
  • First ring in pixel
  • Ring percentage
  • Ring + 1 percentage
  • Ring + 2 percentage

Configurable values file
• Spectrums averaging mode
• Number spectrums to average
• Milliseconds spectrums to average
• Location of Background and Size
• Send image rate
• Calculate background rate
• Time between frames
Science Mode Program Flow

1. Initialize Camera
2. Initialize Send Image Thread
3. Receive/Process Commands
4. Get Image From Camera
5. Calculate Spectrum
6. Send Spectrum Data
7. Check If Time To Send Image
8. Get Lock on Image
9. Copy Image From Shared Memory
10. Release Lock on Image
11. Break Image Into HRT Packets
12. Send HRT Packets
Find Centroid
Find Centroid Cont.

• Tried:
  • Canny edge detector
    • Image too noisy
  • Hough Circles
    • Many false circles and none fit the actual circle
  • Blur/mask procedure
    • 3x3 mask took 40 min
    • 5x5 mask took 2 hours 8 min

• Ended up implementing my own method
Find Centroid Cont.

• Get average value of the four corners
Find Centroid Cont.

• Choose the maximum corner average value and use as threshold
Find Centroid Cont.

• Calculate average of values greater than the previous threshold and use as new threshold
Find Centroid Cont.

• Visit all pixels above threshold and check if its neighbors are also above the threshold
Find Centroid Cont.

- Find edge points and subtract to find the center and radius
Calculate Ring Percentages

- Calculate ring-pixel intersection
- Calculate area under ring
- Calculate area under pixel
- Subtract areas
- Project percentages
Calculate Spectrum

- Check time to see if the average background value needs to be calculated
  - If it does, calculate it
- Go through ring percentages table and multiply percentages to pixels while keeping a sum for each ring
- Calculate averages and add to HRT packet
  - Data Reduction
    - Image Size = 320 pixels * 240 pixels = 76800 pixels * 2 bytes = 153600 bytes
    - Number of rings = 40 * 4 bytes = 160 bytes
    - 153600 bytes/160 bytes = ~960 to 1
- If HRT packet filled, send packet
Calculate Spectrum Cont.

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  - Location: 0, 1
  - Ring #: 2
  - Percent 1: 91
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- **Ring 1:** 2291
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Lessons Learned

• cFE/cFS Apps
• Working with and testing hardware
  • Xilinx Tools
  • Slow down of float values
• Not all gray-scale images have 8 bit pixel values
• Working with scientists
Questions