Development of the Fabry-Perot Spectrometer Application

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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

• **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
- 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

Software Bus Network

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

Software Bus Network

CFE Core Apps  File Manager  Health & Safety  FTDP

CFE Software Bus

CSP App
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

- Initialize Camera
- Initialize Send Image Thread
- Receive/Process Commands
  - Get Image From Camera
  - Calculate Spectrum
  - Send Spectrum Data
- Send Image Thread
  - Check If Time To Send Image
    - Get Lock on Image
      - Copy Image From Shared Memory
      - Release Lock on Image
      - Break Image Into HRT Packets
      - 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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• Pixel 2:
  • Location: 0, 1
  • Ring #: 2
  • Percent 1: 91
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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