Adapting the Reconfigurable SpaceCube Processing System for Multiple Mission Applications

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SCIENCE DATA PROCESSING BRANCH
Code 587 ÂNASA GSFC
SpaceCube Family Overview

v1.0
- 2009 STS-125
- 2009 MISSE-7
- 2013 STP-H4
- 2015 STP-H5

v1.5
- 2012 SMART

v2.0-EM
- 2013 STP-H4
- 2015 STP-H5

v2.0-FLT
- 2015 GPS Demo
  - Robotic Servicing
  - Numerous proposals for Earth/Space/Helio
The Challenge

The next generation of NASA science missions will require “order of magnitude” improvements in on-board computing power.

Mission Enabling Science Algorithms & Applications

- Real-time Wavefront Sensing and Control
- On-Board Data Volume Reduction
- Real-time Image Processing
- Autonomous Operations
- On-Board Product Generation
- Real-time Event / Feature Detection
- Real-time “Situational Awareness”
- Intelligent Data Compression
- Real-time Calibration / Correction
- On-Board Classification
- Inter-platform Collaboration
Our Approach

The traditional path of developing radiation hardened flight processor will not work ... they are always one or two generations behind.

Science data does not need to be 100% perfect, 100% of the time ... occasional “blips” are OK, especially if you can collect 100x MORE DATA using radiation tolerant* processing components.

Accept that radiation induced upsets will happen occasionally ... and just deal with them.

Target 10x to 100x improvement in “MIPS/watt”

*Radiation tolerant – susceptible to radiation induced upsets (bit flips) but not radiation induced destructive failures (latch-up)
Our Solution

**SpaceCube: a high performance reconfigurable science data processor based on Xilinx Virtex FPGAs**

- Hybrid processing ... CPU, DSP and FPGA logic
- Integrated “radiation upset mitigation” techniques
- SpaceCube “core software” infrastructure
- Small “critical function” manager/watchdog
- Standard interfaces

Note: SpaceCube 2.0 and SpaceCube Mini can be populated with either commercial Virtex 5 FX130T parts or radiation hardened Virtex 5 QV parts ... offering system developers the option of trading computing performance for radiation performance
SpaceCube, Target Applications

- Small, light-weight, reconfigurable multi-processor platform for space flight applications demanding extreme processing capabilities
  - Reconfigurable Components: FPGA, Software, Mechanical
  - Promote reuse between applications
- Hybrid Flight Computing: hardware acceleration of algorithms to enable onboard data processing and increased mission capabilities

### Hardware Algorithm Acceleration

<table>
<thead>
<tr>
<th>Application</th>
<th>Xilinx Device</th>
<th>Acceleration vs CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR Altimeter</td>
<td>Virtex-4 FX60</td>
<td>79x vs PowerPC 405 (250MHz, 300 MIPS)</td>
</tr>
<tr>
<td>RNS GNFIR FPU, Edge</td>
<td>Virtex-4 FX60</td>
<td>25x vs PowerPC 405 (250MHz, 300 MIPS)</td>
</tr>
<tr>
<td>HHT EMD, Spline</td>
<td>Virtex-1 2000</td>
<td>3x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
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<tr>
<td>Hyperspectral Data Compression</td>
<td>Virtex-1 1000</td>
<td>2x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
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<tr>
<td>GOES-8 GndSys Sun correction</td>
<td>Virtex-1 300E</td>
<td>6x vs Xeon Dual-Core (2.4GHz, 3000 MIPS)</td>
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</tbody>
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**Notes:**
1. All functions involve processing large data sets (1MB+)
2. All timing includes moving data to/from FPGA
3. SpaceCube 2.0 is 4x to 20x more capable than these earlier systems

### On-Board Data Reduction

**On-board product generation yields factor of 165x data volume reduction**

**Difference < 1%**
SpaceCube v1.0 System

Mechanical Slice Stacking Architecture

Base Unit Size: 4.5” x 4.3” x 3”
Operating Range: -30C to +55C
Power: 12-16W

Processor Slice, Back-to-Back Architecture

FPGAs: 2x Xilinx V4FX60, 2x Aeroflex UT6325
Memory: 1GB SDRAM, 1GB NAND Flash, PROM/SRAM
External I/O: 20ch LVDS/RS422

Power Slice, Two Cards

28V Input, 5V, 3.3V, 2.5V, 1.5V, +/-12V Outputs
External I/O: 1553, 10Base-T Ethernet, 4ch RS422
## SpaceCube v1.0 Missions

<table>
<thead>
<tr>
<th>Year</th>
<th>Mission</th>
<th>Application</th>
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<tr>
<td>11/2009-Present</td>
<td>MISSE7/8</td>
<td>Radiation Experiment</td>
</tr>
<tr>
<td>2010-2011</td>
<td>Argon Robotic Ground Demo</td>
<td>Similar to RNS with additional instruments, upgraded algorithms</td>
</tr>
<tr>
<td>8/2013-Present</td>
<td>STP-H4, DoD Delivery</td>
<td>Payload Control, ISS Interface</td>
</tr>
<tr>
<td>2015</td>
<td>STP-H5, DoD Delivery</td>
<td>Payload Control, ISS Interface</td>
</tr>
</tbody>
</table>

![FPGA High-Level Design Example, RNS](image)

**Leveraged Mechanical, Electrical, FPGA Design, and Flight Software on each subsequent project**

**Reconfigurable System**

\[ \text{Reduced} \text{ $$ and Schedule} \]
RNS Payload on HST-SM4, STS-125

Long Range Camera on Rendezvous

Flight Image

RNS Tracking Solution

Short Range Camera on Deploy

Flight Image

RNS Tracking Solution

RNS SpaceCube

LVPC1

DCC1

AEROFLEX

XILINX

SCuP1

VIM

ACTEL

AEROFLEX

XILINX

LVPC2

DCC2

AEROFLEX

Camera 1

Camera 2

Camera 3

MSM1

MSM2

TM

GPS

KuBand

Compressed Image from HST Release

STS-125 Payload Bay

RNS System: 28 FPGAs
On-Board Image Processing

→ Successfully tracked Hubble position and orientation in real-time operations
→ FPGA algorithm acceleration was required to meet 3Hz loop requirement
MISSE7/8 SpaceCube

Embedded System Diagram

SEU Map

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SpaceCube Upset Mitigation

GSFC SpaceCube v1.0 (Nov 2009):
- “Radiation Hardened by Software” Experiment (RHBS)
- Autonomous Landing Application
- Collaboration with NRL and the DoD Space Test Program (STP)

FPGA and FSW successfully reconfigured on-orbit

MISSE7/8

Data as of 3/1/2014

Days in orbit 1500+
Total SEUs detected & corrected 200+
Total SEU-induced resets 6
Total SEU-induced reset downtime 30 min
Total processor availability 99.9979%
Argon AR&D Test Payload

- Estimated Mass: 140 lb
- Rough Size: 25”x32”x14”

Components:
- IR Camera
- Neptec TriDAR
- SpaceCube (EDU)
- MDA RNS Cameras And Baffles
- Power Control Unit (PCU)
- Wireless Patch Antennas (x4)
- Wireless Experiment Box (WEB)
- Ball VNS
- Wireless Patch Antennas
- Ecliptic/Sony Situational Awareness Camera
- Spacecraft Mount
- TriDAR
→ Embedded system consisted of 8 PowerPC405s
→ Reconfigurable system to support various instrument payloads
Testing with simulated 6-DOF motion of Argon and Target
- Rotopod and FANUC motion platforms simulate target-sensor dynamics
- Up to 13 m separation possible

Testing conducted at GSFC in January-February 2012
- Motion includes closed-loop approach and non-cooperative “tumble”
- Open loop testing to characterize sensor/algorithm performance
- Closed-loop tests - evaluate end-to-end system (sensors, algorithms, control law) in real time
SpaceCube CIB, STP-H4

- Delivery to Space Test Program
- Interfaces with ELC and 8 attached payloads

Days in orbit: 200+
Total SEUs detected & corrected: 20+ (as of 3/1/2014)
Total SEU-induced resets: 1
STP-H4 Operational on ISS

Next Up: STP-H5 and Robotic Refueling Mission 3 in 2015
System Reuse and Reconfiguration

RNS
- Drawings Procedures
- Core Software
- Embedded System
- Scrubber
- Image Processing
- Video Compression

MISSE-7
- SDRAM EDAC
- Design File Upload
- RHBS
- Ground Station

Argon
- 1553
- Ethernet
- AR&D Upgrade
- Processor Network

CIB

SpaceCube v2.0 Systems and Missions

Interface Card
- JPEG Comp Slice
- Splitter Slice
- Video Interface Slice
- Not Required
Conclusions

- Designing a new system has significant non-recurring engineering cost
- Firm embedded system infrastructure and reconfigurable file structure is critical
- A reconfigurable and adaptable system enables low-cost, quick-turn missions
- A scalable mechanical/electrical system can easily adapt to new interface requirements
- Reconfigurable system enables accelerated requirements creep: **BE FIRM!**