HyspIRI Intelligent Payload Module (IPM) and Benchmarking Algorithms for Upload

Dan Mandl/GSFC

5-4-10
HyspIRI Low Latency Data Production Concept

20 MBPS Direct Broadcast
(Net downlink throughput – 10 Mbps)
Downlink:
- Select Spectral Bands
- Select L-2 Products
Continuous Earth-view Broadcast

130.2 Mbps Multispectral Thermal InfraRed (TIR) Scanner

804 Mbps Hyperspectral Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

Spectral
- Bands (8) 3.98 μm, 7.35 μm, 8.28 μm, 8.63 μm, 9.07 μm, 10.53 μm, 11.33 μm, 12.05 μm

Spatial
- IFOV 60 m
- Range 600 km (25.3 at 626 km)
- Cross-Track Samples >2560
- Sampling 60 m
HyspIRI Data Flow

- **TIR**
- **VSWIR**
- **Command & Data Handling Solid State Recorder**

**IPM**

**Direct Broadcast Module**

- **130.2 Mbps**
- **804 Mbps**

**Command and Data Handling Solid State Recorder**

- **Spacecraft**
- **To/From Alaska and Norway Ground Stations**

- **S-band command**
- **S-band housekeeping data**
- **X-band 800 Mbps Science data**

**Direct Broadcast Antennas**

**20 Mbps**
HyspIRI VSWIR Data Processing Architecture Only

- Each data stream has \( \frac{1}{4} \) swath (~36km) all spectral bands
- PPC = Power PC
- LEON and MicroBlaze are types of flight processors
  - Orchestrate PPC activity augmented by Field Programmable Arrays (FPGA)

**Visible Short Wave Infrared Imager (VSWIR)**

- 200 Mbps hyperspectral data
- 200 Mbps hyperspectral data
- 200 Mbps hyperspectral data
- 200 Mbps hyperspectral data

**TBD GB Flash Storage**

**LEON or MicroBlaze**

**20 Mbps Download (10 Mbps actual throughput)**
Testbed Approach for HyspIRI IPM VSWIR Processing

- 5 seconds of HyspIRI data captured at a time by PPC processors - 38 km x 34 km (640 pixels x 565 pixels x 213 bands)
  - Flight software will process 4 quarter swath HyspIRI Scenes in parallel
  - Migrate band stripping to FPGA’s later
  - Each PPC processor will ping pong HyspIRI scenes, processing one scene while the next is flowing into memory
- Each 5 second scene will require 616 MB memory
- Scenes will be stored in memory in band sequential order in an array of words

![Diagram of HyspIRI Scene and Wide-scene](image)
## Low Fidelity HyspIRI IPM Testbed

### Features

- **Hardware**
  - Xilinx Virtex-5 (SpaceCube 2)
  - 2 x 400MHz PPC
  - 100MHz Bus
  - 2 x 512MB SDRAM
  - Dual Gigabit Ethernet
- Support Linux kernel 2.6.31 (gcc version 4.2.2)
- Support software running in standalone mode for better performance
- Can stream raw data up to 800 Mbps
- Ready for operations

### Software Application Examples

- Band-stripping
- Algorithms: cloud, sulfur, flood, thermal, SWIL, NDVI, NDWI, SIWI, oil spills, algae blooms, etc.
- Corrections: geometric, radiometric, atmospheric
- Core Flight System / dynamic software bus
- CCSDS File Delivery Protocol
- Delay Tolerant Network
- CASPER / onboard planning
- Fault monitoring / recovery software
- S/C command and telemetry software
- Data compression
- Sensor Web for Autonomous Mission Operations
Low Fidelity HyspIRI IPM Testbed

Data Generator Workstation
• Generates test data and streams it to the board at rate up to 800Mbps.

NETGEAR Gigabit Switch
• Allows the board and the data generator workstation to connect at Gigabit speed.

Compact Flash
• Ext3 formatted file system with Linux libraries and tools

Platform Cable USB
• Provides an easy method for debugging software running on the board

Virtex-5 FPGA
• SpaceCube 2 core FPGA
• Configured as dual 400MHz PPC design
• Capable of running with Linux or in a standalone mode

Xilinx ML510 Development Board
• Enables the development team to verify the Virtex-5 while the SpaceCube 2 is finalizing the design
### Initial Benchmark Results

#### 32-bit Memory Test

<table>
<thead>
<tr>
<th>32-bit Memory Test</th>
<th>Write (ms)</th>
<th>Read + Verify (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>128MB</td>
<td>711</td>
<td>1179</td>
</tr>
<tr>
<td>256MB</td>
<td>1564</td>
<td>2365</td>
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<tr>
<td>512MB</td>
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<td>4731</td>
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<tr>
<td>1024MB</td>
<td>6673</td>
<td>10670</td>
</tr>
</tbody>
</table>

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**Disclaimer:** Code not optimized. Performance based on a 400MHz PPC design.

#### Algorithms

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Linux (ms)</th>
<th>Standalone (ms)</th>
<th>Linux (ms)</th>
<th>Standalone (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EO1 scene (256 x 1000 pixels)</strong></td>
<td></td>
<td><strong>HyspIRI ¼ swath (640 x 565 pixels)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud</td>
<td>1791</td>
<td>431</td>
<td>2170</td>
<td>589</td>
</tr>
<tr>
<td>Flood</td>
<td>3024</td>
<td>937</td>
<td>3782</td>
<td>1311</td>
</tr>
<tr>
<td>SWIL</td>
<td>7350</td>
<td>2872</td>
<td>10226</td>
<td>4058</td>
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<tr>
<td>Sulfur</td>
<td>116362</td>
<td>29515</td>
<td>164978</td>
<td>42026</td>
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<tr>
<td>Thermal</td>
<td>1103</td>
<td>304</td>
<td>1475</td>
<td>431</td>
</tr>
<tr>
<td>SIWI</td>
<td>580</td>
<td>44</td>
<td>823</td>
<td>62</td>
</tr>
<tr>
<td>NDVI</td>
<td>630</td>
<td>44</td>
<td>904</td>
<td>62</td>
</tr>
<tr>
<td>NDWI</td>
<td>589</td>
<td>44</td>
<td>836</td>
<td>62</td>
</tr>
</tbody>
</table>

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Not Optimized! FPGA not leveraged
Other CPU IPM Processor Benchmarks

Cloud benchmark pixels detected as a cloud in blue

bands (21, 31, 51, 110, 123, 150)

<table>
<thead>
<tr>
<th>GSFC Benchmark</th>
<th>MHz</th>
<th>Thermal CPU%</th>
<th>Cloud CPU%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeroflex LEON3</td>
<td>75</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>BAE RAD750</td>
<td>133</td>
<td>50</td>
<td>80</td>
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<tr>
<td>Xilinx PPC 440</td>
<td>440</td>
<td>20</td>
<td>30</td>
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</table>

<table>
<thead>
<tr>
<th>JPL Benchmark</th>
<th>MHz</th>
<th>Thermal CPU%</th>
<th>Cloud CPU%</th>
<th>Flood CPU%</th>
<th>SWIL SVM CPU%</th>
<th>SULPHUR SVM CPU%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mongoose V</td>
<td>12</td>
<td>tbd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmel LEON2</td>
<td>100</td>
<td>597</td>
<td>684</td>
<td>823</td>
<td>1784</td>
<td>14935</td>
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<tr>
<td>RAD750</td>
<td>200</td>
<td>294</td>
<td>383</td>
<td>441</td>
<td>1030</td>
<td>4856</td>
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<tr>
<td>GESPEC</td>
<td>150</td>
<td>166</td>
<td>190</td>
<td>230</td>
<td>520</td>
<td>2202</td>
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<tr>
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<td>156</td>
<td>181</td>
<td>299</td>
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<td>23223</td>
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<tr>
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<td>120</td>
<td>156</td>
<td>180</td>
<td>421</td>
<td>1985</td>
</tr>
</tbody>
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- Benchmark numbers need reconciliation to understand differences
- More sophisticated algorithms will clearly require FPGA acceleration

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August 11-13, 2009
## Vision for Development of IPM Process Chain

<table>
<thead>
<tr>
<th>Processes</th>
<th>Ground</th>
<th>Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Level 1R</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Atmospheric Correction</td>
<td>Automation in progress</td>
<td>-</td>
</tr>
<tr>
<td>Dynamic Algorithms</td>
<td>JPL WCPS/SWAMO</td>
<td>In Testbed</td>
</tr>
<tr>
<td>Geometric Correction</td>
<td>L1G</td>
<td>-</td>
</tr>
<tr>
<td>Compression</td>
<td>CCSDS</td>
<td>Card Available</td>
</tr>
<tr>
<td>Downlink</td>
<td>N/A</td>
<td>-</td>
</tr>
</tbody>
</table>
One Possible HyspIRI IPM Ops Concept

1. create, edit, test algorithms/classifiers for use onboard space-based sensors
2. transform algorithm into mobile agent
3. upload mobile agent
4. run onboard automatically
5. download customized low-latency onboard generated data products

HyspIRI Intelligent Payload Module (IPM)

Image data products-
Phil Dennison 2008