Next Generation UAS Based Spectral Systems for Environmental Monitoring

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\textsuperscript{e}California State University, Monterey Bay, CA

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CalTech Pasadena, CA
Scales at which remote sensing spectral measurements are currently made with gap

The Unmanned Serial System (UAS) sensors are bridging the gap between ground and higher altitude aircraft data.
PROJECT GOALS

- Goal is to produce in 2 years (June 2015 – May 2017) science-quality spectral data from UAS suitable for scaling ground measurements and comparison against airborne or satellite sensors.

- We will develop protocols and a workflow to ensure that VNIR measurements from UAS’s are collected and processed in a fashion that allows ready integration or comparison to NASA satellite and airborne data and derived products (e.g. Landsat, AVIRIS EO-1 Hyperion and future HyspIRI).
Objectives

Develop the UAS capability to:
• Retrieve *biochemical and physiological traits*
• Depict diurnal and seasonal cycles in vegetation function,
• Optimize UAS spectral data acquisition and workflows, to develop a small UAS hyperspectral using SensorWeb components
• Produce science-quality spectral data and biophysical parameters (BP), suitable for scaling ground measurements and comparison to from-orbit data products.
To characterize ecosystem biochemical and physiological parameters we will use: reflectance (a) and solar-induced fluorescence (b).

We will use high spectral resolution discrete measurements (Yr1) and imaging spectroscopy (Yr2).
Workflow for retrieval of Biophysical Parameters (BPs), validation and improvement (after Vuolo et al. 2012).

TOC – Top of canopy
CBP - Canopy Biophysical Properties
R - Reflectance
UASs SensorWeb capabilities

Near real time processing to re-plan during sortie.

Intelligent Collection

IPM Onboard Processing

- Biophysical Micro Mapping
- Extend In-Situ Measurements
- Spatial Scaling Analyses
- Next Generation Observation Strategies

Sensor Web Interface and Dashboard Distribution

SCALING...

Synoptic View

Bridging gaps to connect *in situ* with airborne and orbital observations.
SensorWeb and IPM Definition

• SensorWeb - a set of sensors (land, marine, air, space) and processing which interoperate in a (semi) automated collaborative manner for scientific investigation, disaster management, resource management, and environmental intelligence”.

  – More information at:  http://sensorweb.nasa.gov

• Intelligent Payload Module (IPM) - Adapter for SensorWeb for high speed sensor data which is a combination of flight hardware and flight software that provides data subsets and/or higher level data products in near real time or realtime
Original Driving Operations Concept for IPM

Level 0
- 500 – 1000 Mbps Instrument data rate
- Raw data processed to remove artefacts

Level 1R
- Apply Radiometric Correction to each pixel

Atmospheric Correction
- Convert radiance to reflectance

Geometric Correction
- Tag each pixel with correct location information

Level 2 Classification
- Run Web Coverage Processing Service to run algorithm against data (e.g. spectral angle mapper, vectorizer)

Downlink RT Algal Bloom Maps to Users on Bay 10 Mbps
Original Intelligent Payload Module Box v1 – Hardware Developed Under AIST-11 “A High Performance Onboard Multicore Intelligent Payload Module for Orbital and Suborbital Remote Sensing Missions

- 14.5 x 14.5 x 7 inches
- Wide-Input-Range DC voltage (6V-30V)
- Made of strong durable aluminum alloy
- Dual mounting brackets
- Flush design
- Removable side panels
- Mounting racks are electrically isolated from the box
- Electronic components
  - Tilera development board (TILEPro64)
  - Xilinx Zynq development board (MicroZed)
  - Single board computer (Dreamplug)
  - 600GB SSD
  - Gigabit Ethernet switch
  - Transceiver radio
  - Power board
Original Integration and Flights of IPM and Hyperspectral Instrument Box on Bussmann Helicopter

- 7/16/2014 – Manassas Airport Area – Test flight
  - Had EMI problems, interfering with Pilot Aviation Bands 118 MHz to 137MHz
  - Had imaging problems due to software bug
- 7/23/2014 – Manassas Airport Area – Test flight
  - Had EMI problems – Tilera CPU is leaking 125MHz signal
- 9/24/2014 – Manassas Airport Area – Test flight
  - Had imaging problems due to the shutter
- 1/20/2015 – Manassas Airport Area
  - Successful Flight
- 4/13/2015 – Patuxent Environmental & Aquatic Research Laboratory (PEARL) Center Flight from Manassas (Leaf Off)
  - Successful Flight
Original Hyperspectral Data Processing Software on IPM

- Ingest/Level 0 (chai-l0)
- Radiometric Correction (chai-l1r)
- Atmospheric Correction (FLAASH)
- Geometric Correction (GCAP)
- Level 2 Product Data (WCPS)

Message Bus

- Command Ingest (ci)
- Telemetry Output (to)

FreeWave MM2 900MHz / 153.6Kbps

ASIST Telemetry and Command System

CMD DB

TLM DB

DB - Database
IPM Test Flight Bussmann Helicopter
April 13\textsuperscript{th} 2015 / St. Leonard, MD at the
Patuxent Environmental and Aquatic Research Lab (PEARL) – Morgan State Univ.

Maureen Kelly
Faculty Research Assistant UMD
mkelly17@umd.edu
IPM Test Flight Bussmann Helicopter
April 13th 2015 / St. Leonard, MD at the
Patuxent Environmental and Aquatic Research Lab (PEARL) – Morgan State Univ.
Evolving Set of Platforms Targeted for IPM

USFS King Air B200

Contract MD 500C

USFS Cessna Citation

NASA Cessna 206H

Rotorcraft Drone

HyspIRI

ISS Optical Window

Hexacopter (This effort)

Intelligent Payload Module

Landsat 9
IPM as an Evolving Platform Integrating HW and SW Components

**HW Components**

- SpaceCube 1.0
- Tilera Tile64 TileGX
- Zynq ZC7020
- SpaceCube 2.0 PowerPC Virtex5
- CHREC Space Processor Cubesat ARM/Zynq FPGA
- Processors with nano-material

**SW Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>2005</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IPM Weight</strong></td>
<td>5-20 lbs</td>
<td></td>
<td></td>
<td>&lt;1 lb</td>
</tr>
<tr>
<td><strong>IPM Power</strong></td>
<td>20 – 80 watts</td>
<td></td>
<td>&lt;10 watts</td>
<td>&lt;2-3 watts</td>
</tr>
<tr>
<td><strong>IPM Clock</strong></td>
<td>100 Mhz – 800 Mhz</td>
<td></td>
<td>&gt;300 Mhz</td>
<td></td>
</tr>
<tr>
<td><strong>Data Throughput</strong></td>
<td>50 kbps – 1 Gbps</td>
<td></td>
<td>&gt;10 Gbps</td>
<td></td>
</tr>
</tbody>
</table>
IPM for This Effort

• Shrink IPM: Using MicroZed Z-7020 in smaller box
  ➢ Based on Zynq chip, 2 ARM processors, 53K look-Up tables and 100K gates

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Z-7010</th>
<th>Z-7015</th>
<th>Z-7020</th>
<th>Z-7030</th>
<th>Z-7035</th>
<th>Z-7045</th>
<th>Z-7100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Number</td>
<td>XC7Z010</td>
<td>XC7Z015</td>
<td>XC7Z020</td>
<td>XC7Z030</td>
<td>XC7Z035</td>
<td>XC7Z045</td>
<td>XC7Z100</td>
</tr>
<tr>
<td>Xilinx 7 Series Programmable Logic Equivalent</td>
<td>Artix-7 FPGA</td>
<td>Artix-7 FPGA</td>
<td>Artix-7 FPGA</td>
<td>Kintex®-7 FPGA</td>
<td>Kintex-7 FPGA</td>
<td>Kintex-7 FPGA</td>
<td>Kintex-7 FPGA</td>
</tr>
<tr>
<td>Programmable Logic Cells (Approximate ASIC Gates) (3)</td>
<td>28K Logic Cells (~430K)</td>
<td>74K Logic Cells (~1.1M)</td>
<td>85K Logic Cells (~1.3M)</td>
<td>125K Logic Cells (~1.9M)</td>
<td>275K Logic Cells (~4.1M)</td>
<td>350K Logic Cells (~5.2M)</td>
<td>444K Logic Cells (~6.4M)</td>
</tr>
<tr>
<td>Look-Up Tables (LUTs)</td>
<td>17,600</td>
<td>46,200</td>
<td>53,200</td>
<td>78,600</td>
<td>171,900</td>
<td>218,600</td>
<td>227,300</td>
</tr>
<tr>
<td>Flip-Flops</td>
<td>35,200</td>
<td>92,400</td>
<td>106,400</td>
<td>157,200</td>
<td>343,800</td>
<td>437,200</td>
<td>554,800</td>
</tr>
<tr>
<td>Extensible Block RAM (if 36 Kb Blocks)</td>
<td>240 KB (60)</td>
<td>380 KB (95)</td>
<td>560 KB (140)</td>
<td>1,060 KB (265)</td>
<td>2,000 KB (500)</td>
<td>2,180 KB (545)</td>
<td>3,020 KB (755)</td>
</tr>
<tr>
<td>Programmable DSP Slices (18x25 MACCs)</td>
<td>80</td>
<td>160</td>
<td>220</td>
<td>400</td>
<td>900</td>
<td>900</td>
<td>2,020</td>
</tr>
</tbody>
</table>

• FPGA fabrics are mostly programmable logic slices: look-up-tables (LUTs) and registers together in a larger block
• Theoretically, logic slices could implement anything, but “hard” ASIC logic is often faster and more efficient
IPM for This Effort

• Image aided navigation
  ✓ Onboard processing of data processing chain of hyperspectral data from *Piccolo Doppio* spectrometer and Headwall Nano-hyperspec or equivalent imaging spectrometer
  ✓ Data subsetting
  ✓ Real time campaign/way point adjustments based on measurements and objectives (autonomous scheduling, goal oriented abstraction)
    o Possible use of Autonomous Sciencecraft Experiment (presently used on EO-1)

• Data product distribution to dashboard and possible use of social media (GeoSocial API, onboard publisher, ground consumer)
Z-7020 – Zynq (ARM/FPGA Processor) Proxy for COTS+RH+FTC CHREC Space Processor (CSP)

**COTS**
- Zynq-7020 hybrid SoC
  - Dual ARM A9/NEON cores
  - Artix-7 FPGA fabric + hard IP
- DDR3 memory

**RadHard**
- NAND flash
- Power circuit
- Reset circuit
- Watchdog unit

**FTC = Fault-Tolerant Computing**
- Variety of mechanisms
  - External watchdog unit to monitor Zynq health and reset as needed
  - RSA-authenticated bootstrap (primary, secondary) on NAND flash
  - ECC memory controller for DDR3 within Zynq
  - ADDAM middleware with message, health, and job services
  - FPGA configuration scrubber with multiple modes
  - Internal watchdogs within Zynq to monitor behavior
  - Optional hardware, information, network, software, and time redundancy
CHREC Space Processor on ISS and Cubesat

- CSP/SpaceCube Tech Demo ISIM (Space Station)
  - 2 CSP’s, SpaceCube 1.0, 1.5, 2.0
  - Delivered to DoD early FY15 and launched early FY16
  - Gary Crum/587
- Compact Radiation BElt Explorer (CeREs) is part of NASA's Low-Cost Access to Space program
  - 3U Cubesat
  - 1 CSP
  - Delivery to GSFC early 2015, Launch 2016
Publisher/Consumer/GeoSocial API Architecture

A methodology to rapidly discover, obtain and distribute satellite data products via social network and open source software
Basic SensorWeb Architecture
## GSFC SensorWeb Components (Ground)

<table>
<thead>
<tr>
<th>SensorWeb Toolkit Subsystem</th>
<th>Type</th>
<th>NTR</th>
<th>How long in operation</th>
<th>TRL</th>
<th>Developed Under</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>SensorWeb Reference Architecture</td>
<td>Arch</td>
<td>GSC-5025286</td>
<td>7 years +</td>
<td>9</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>Campaign Manager (GeoBPMS)</td>
<td>WfCS</td>
<td>GSC-16267-1</td>
<td>5 years</td>
<td>9</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>Campaign Manager Client</td>
<td>WfCS</td>
<td>GSC-5027514</td>
<td>2 years</td>
<td>7</td>
<td>AIST-05</td>
<td>Not used</td>
</tr>
<tr>
<td>Identity Management Services</td>
<td>Security</td>
<td>GSC-16268-1</td>
<td>5 years</td>
<td>9</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>EO-1 SPS 0.3 (GSFC)</td>
<td>SPS</td>
<td>GSC-16271-1</td>
<td>5 years</td>
<td>9</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>EO-1 SOS</td>
<td>SOS</td>
<td>GSC-16272-1</td>
<td>5 years</td>
<td>7</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>OGC Publish/Subscribe Basic</td>
<td>WNS</td>
<td>GSC-16270-1</td>
<td>5 years</td>
<td>9</td>
<td>AIST-05</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>WCPS</td>
<td>WCPS</td>
<td>GSC – 16273-1</td>
<td>3 years</td>
<td>9</td>
<td>AIST-08</td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>Weka to WCPS Translator</td>
<td>WCPS</td>
<td>GSC-16274-1</td>
<td>3 years</td>
<td>7</td>
<td>AIST-08</td>
<td>Not used</td>
</tr>
<tr>
<td>Flood Dashboard</td>
<td>DADM</td>
<td>GSC-16275-1</td>
<td>3 years</td>
<td>9</td>
<td>EO-1</td>
<td>Active Namibia, Central America, others</td>
</tr>
<tr>
<td>GeoSocial API</td>
<td>WfCS</td>
<td>GSC-17162-1</td>
<td>0 years</td>
<td>6</td>
<td>AIST-QRS11</td>
<td>Namibia, Central America, others</td>
</tr>
<tr>
<td>Flood Vectorization Topojson</td>
<td>WCPS</td>
<td>GSC-17169-1</td>
<td>0 years</td>
<td>6</td>
<td>TBS</td>
<td>Demo mode</td>
</tr>
<tr>
<td>Geo-Registration of Multi-Source Image Data</td>
<td>WCPS</td>
<td>GSC-16862-1</td>
<td>0 Years</td>
<td>6</td>
<td>TBS</td>
<td>Demo mode</td>
</tr>
</tbody>
</table>

Arch- Architecture  
WfCS – Workflow Chaining Service  
SPS – Sensor Planning Service  
WCPS – Web Coverage Processing Service  
WNS – Web Notification Service  
DADM – Data Aggregator and Display Mashup
## JPL SensorWeb Components (Ground)

<table>
<thead>
<tr>
<th>SensorWeb Toolkit Subsystem</th>
<th>Type</th>
<th>NTR</th>
<th>How long in operation</th>
<th>TRL</th>
<th>Developed Under</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intelligent Payload Module</td>
<td>WfCS</td>
<td>JPL-45445</td>
<td>6 years</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>MODIS-based Flood Detection, Tracking and Response</td>
<td>WfCS</td>
<td>JPL-48148</td>
<td>6 years +</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>Change based satellite monitoring using broad coverage targetable sensors</td>
<td>WfCS*</td>
<td>JPL-48147</td>
<td>7 years</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>EO-1 SPS 2.0</td>
<td>SPS</td>
<td>JPL-48142</td>
<td>5 years +</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>WPS Software Framework</td>
<td>WPS</td>
<td>JPL-45998</td>
<td>6 years</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
<tr>
<td>Autonomous Hyperspectral Data Processing/Dissemination</td>
<td>WfCS*</td>
<td>JPL-48123</td>
<td>7 years</td>
<td>9</td>
<td></td>
<td>Active on EO-1</td>
</tr>
</tbody>
</table>

Arch- Architecture  
WfCS – Workflow Chaining Service  
SPS – Sensor Planning Service  
WNS – Web Notification Service  
WCPS – Web Coverage Processing Service  
DADM – Data Aggregator and Display Mashup  
* - Noncompliant with OGC Standards
**IPM SensorWeb Internal SW Components (Onboard)**

<table>
<thead>
<tr>
<th>SensorWeb Toolkit Subsystem</th>
<th>Type</th>
<th>NTR</th>
<th>How long in operation</th>
<th>TRL</th>
<th>Developed Under</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intelligent Payload Module</td>
<td>WfCS</td>
<td>GSC-16867-1</td>
<td>Assorted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cFE command in integrated into IPM</td>
<td>-Til</td>
<td>6 months</td>
<td>7</td>
<td>Active Bus helo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cFE telemetry out integrated into IPM</td>
<td>-Til</td>
<td>6 months</td>
<td>7</td>
<td>Active Bus helo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cFE CFDP integrated into IPM</td>
<td>-Til</td>
<td>6 months</td>
<td>7</td>
<td>Active Bus helo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WCPS integrated into IPM</td>
<td>-Til</td>
<td>6 months</td>
<td>7</td>
<td>Active Bus helo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- GCAP single processor</td>
<td>-Til</td>
<td>6 months</td>
<td>6</td>
<td>Active Bus help</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- GCAP parallel processed on multicore</td>
<td>-Til</td>
<td>6 months</td>
<td>6</td>
<td>Active on testbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- FLAASH Atmospheric Corr, one proc</td>
<td>- Til</td>
<td>6 months</td>
<td>5</td>
<td>Active on testbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- FLAASH Atmospheric Corr, parallel</td>
<td>- Til</td>
<td>6 months</td>
<td>4</td>
<td>Active on testbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Spectral Angle Mapper</td>
<td>- Til</td>
<td>6 months</td>
<td>6</td>
<td>Active Bus helo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Instrument data ingest</td>
<td>- FPGA</td>
<td>6 months</td>
<td>3</td>
<td>Helo/cubesat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- FLAASH AC</td>
<td>- FPGA</td>
<td>6 months</td>
<td>3</td>
<td>Helo/cubesat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- GCAP</td>
<td>- FPGA</td>
<td>6 months</td>
<td>3</td>
<td>Helo/cubesat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Architectures and Services**
- **WFCS** – Workflow Chaining Service
- **SPS** – Sensor Planning Service
- **WNS** – Web Notification Service
- **WCPS** – Web Coverage Processing Service
- **DADM** – Data Aggregator and Display Mashup
- **Til** – on Tilera multicore
- **GCAP** – Geocorrection for Airborne Platforms
- **Noncompliant with OGC Standards**
KEY MILESTONES and TECHNICAL APPROACH

• Integrate and test Ocean Optics spectrometer and Piccolo Doppio upwelling/downwelling foreoptic onto UAS, and establish calibration protocols
• Parameter retrieval and validation of measurements at well-characterized sites
• Develop Rapid Data Assimilation and delivery system, based on SensorWeb Intelligent Payload Module high speed onboard processing developed under AIST-11 and other cloud based data processing chain functionality (http://sensorweb.nasa.gov);
• Develop data gathering campaign strategy to optimize data yield;
• Leverage EcoSIS online spectral library
• Integration of Headwall imaging spectrometer, inter-calibration to Piccolo Doppio
• Validate real-time computing capacity
• Parameter retrieval maps and validation against field data
• Data Production Pipeline Demo
This research effort will enable the acquisition of science-grade spectral measurements from UASs.

The UAS collections at 10-150m altitude would bridge the gap between ground/proximal and airborne measurements, typically acquired at 500m and higher, allowing better linkage of comparable measurements across the full range of scales from ground to satellites.
Backup
Original Hyperspectral Instrument used
- Chai v640 Instrument Box

- 12 x 10 x 7 inches
- Wide-Input-Range DC voltage (6V-30V)
- Made of strong durable aluminum alloy
- Dual mounting brackets
- Flush design
- Removable side panels
- Mounting racks are electrically isolated from the box
- Electronic components
  - CHAI V640
  - Frame Grabber
  - Systron SDN500
  - UNIBLITZ Shutter Driver
  - USB Hub
  - Phidgets Temperature Sensor
Bussmann Helicopter Flights

- **7/16/2014** – Manassas Airport Area – Test flight
  - Had EMI problems, interfering with Pilot Aviation Bands 118 MHz to 137MHz
  - Had imaging problems due to software bug

- **7/23/2014** – Manassas Airport Area – Test flight
  - Had EMI problems – Tilera CPU is leaking 125MHz signal

- **9/24/2014** – Manassas Airport Area – Test flight
  - Had imaging problems due to the shutter

- **1/20/2015** – Manassas Airport Area
  - Successful Flight

- **4/13/2015** – Patuxent Environmental & Aquatic Research Laboratory (PEARL) Center Flight from Manassas (Leaf Off)
  - Successful Flight
Next Generation UAV Spectral Systems for Environmental Modeling

PI: Petya Campbell, UMBC

Objective

- Develop capability to depict diurnal and seasonal cycles in vegetation function:
  - accurate measurements of vegetation reflectance at high spectral resolution
  - high temporal frequencies and stability
  - Spatial variability with high resolution
  - Optimize data acquisition and workflow
- Demonstrate the capability to produce science-quality spectral data from UAVs
  - suitable for scaling ground measurements
  - comparison to from-orbit data products
- Small UAV hyperspectral sensor-web, filling the gap between ground and satellite measurements

Approach:

- Integrate and test Ocean Optics spectrometer and Piccolo upwelling/downwelling foreoptic onto UAV.
  - Validate measurements at well-characterized sites.
- Develop Rapid Data Assimilation and delivery system.
- Develop data gathering campaign strategy to optimize data yield.
  - Leverage EcoSIS online spectral library.

Cols: P. Townsend (lead), C. Kingdon and F. Navarro, UW; D. Mandl (lead) and V. Ly, GSFC; V. Ambrosia, CSUMB; P. Cappelaere, Vightel; L. Corp, Sigma Space; J. Nagol and R. Sohlberg, UMD; L. Ong, SSAI.

Key Milestones

- **Start Project** 06/15
- Spectrometer integration 07/15
- Calibration protocol, intercalibration (initial) 09/15
- Preliminary parameter retrievals and validation 11/15
- Integration of Headwall imaging spectrometer 02/16
- Validate computing capacity for real-time 12/16
- Parameter retrieval/validation against field data 12/16
- **Data Production Pipeline Demo (TRL 5)** 05/17

**TRL_{in} = 3**
IPM Test Flight Bussmann Helicopter
April 13th 2015 / St. Leonard, MD

20150413_A1  20150413_A2  20150413_B1  20150413_B2
IPM Test Flight Bussmann Helicopter
April 13th 2015 / St. Leonard, MD

20150413_C1  20150413_C2  20150413_D1  20150413_D2
IPM Test Flight Bussmann Helicopter
April 13th 2015 / St. Leonard, MD
IPM Test Flight Cessna 206
May 5th 2015 / St. Leonard, MD

20150505_A1  20150505_B2  20150505_C1  20150505_D1
IPM Test Flight Cessna 206
May 27th 2015 / St. Leonard, MD
### Preliminary Metrics for Hyperspectral Image Processing using Multicore CPU and FPGA

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Radiometric Correction (chai-l1r)</th>
<th>*Atmospheric Correction (FLAASH)</th>
<th>Geometric Correction (chai-l1g)</th>
<th>Product Data (WCPS - vis_composite)</th>
<th>Co-registration (ureg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>864 MHz TILEPro64 (1 core)</td>
<td>59.217</td>
<td>1298.600</td>
<td>185.249</td>
<td>44.21</td>
<td>33.18</td>
</tr>
<tr>
<td>864 MHz TILEPro64 (49 cores)</td>
<td>10.195</td>
<td>906.440</td>
<td>4.953</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.0 GHz TILE-Gx36 (1 core)</td>
<td>30.053</td>
<td>505.102</td>
<td>31.229</td>
<td>12.41</td>
<td>6.78</td>
</tr>
<tr>
<td>1.0GHz TILE-Gx36 (36 cores)</td>
<td>2.166</td>
<td>381.620</td>
<td>1.017</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>667MHz ARM ZC702 (1 core)</td>
<td>17.827</td>
<td>323.550</td>
<td>10.861</td>
<td>5.12</td>
<td>3.44</td>
</tr>
<tr>
<td>667MHz ARM ZC702 (2 cores)</td>
<td>10.077</td>
<td>283.880</td>
<td>5.442</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2.2GHz Intel Core i7 (1 core)</td>
<td>0.723</td>
<td>32.161</td>
<td>0.643</td>
<td>0.514</td>
<td>0.386</td>
</tr>
<tr>
<td>2.2GHz Intel Core i7 (4 cores)</td>
<td>0.472</td>
<td>28.700</td>
<td>0.139</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FPGA (Zynq 7Z020)</td>
<td>Implemented</td>
<td>Optimizing fit</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Unit is in seconds  
TILEPro64 – No floating point support  
TILE-Gx36 – Partial floating point support  
* Indicates time includes file I/O

Compiled with "-g -O2 -funroll-loops -fomit-frame-pointer -march=native -fopenmp"

---

**CHAI V640**
- Samples: 696
- Lines: 1800
- Bands: 283
- Data Type: 12 (UINT16)
- Data Rate: 174 Mbps

**Raw Data:**
- Raw Data: 1305.5184 MB
- Level 0: 1304.5248 MB
- Level 1R: 709.0848 MB
ASD Measurements at MSU PEARL

Brandywine Chai 640

Algae Samples

ASD Spectra Measurements @ CHAI 640 wavelengths From 350 to 800 nm

Note: 800nm to 1050nm seemed too noisy
Conversion To ~Reflectance

- Calculated Average White Panel Radiance At All Wavelengths
- Divided All Bands by White Panel Radiances To Generate ~Reflectance
- Generated Composite Visible Image For Validation
- Uploaded The Three Spectra To WCPS
rgb_composite (122,86,53)
SAM golden_algae (cos\(\Theta\)=.93)
SAM blue_green_algae (cos\(\Theta\)=.93)
SAM Diatom

Diatom Algae Bucket

Not enough separation, angle threshold too wide open
Calibration Exercise February 27, 2014 at Pearl Center After Making ChaiV640 SW Adjustments to Get Better Instrument Response

Test setup with ChaiV640 and algae

Images of Algae with from ChaiV640

Measurements with spectrometer for calibration plates and algae
Brandywine Compact Hyperspectral Advanced Imager (CHAI v640)

### SPECIFICATIONS

<table>
<thead>
<tr>
<th>MECHANICALS</th>
<th>ESTIMATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (with lens)</td>
<td>125 x 101 x 75 mm</td>
</tr>
<tr>
<td>Size (with telescope)</td>
<td>200 x 101 x 75 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>0.48 kg (.99 lbs)</td>
</tr>
<tr>
<td>Power</td>
<td>20 watts</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-20 to +50 °C</td>
</tr>
<tr>
<td>Size does not include XS/GPS</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPTICS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrometer Type</td>
<td>Dyson</td>
</tr>
<tr>
<td>Telescope</td>
<td>All-reflective telescope</td>
</tr>
<tr>
<td>Field of View</td>
<td>40 degrees</td>
</tr>
<tr>
<td>Cross Track Pixels</td>
<td>640</td>
</tr>
<tr>
<td>F-Number</td>
<td>f/2</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>350-1080 nm (Reflective)</td>
</tr>
<tr>
<td></td>
<td>400-1000 nm (Refractive)</td>
</tr>
<tr>
<td>Smile Distortion</td>
<td>&lt; 0.1 pixels</td>
</tr>
<tr>
<td>Keystone Distortion</td>
<td>&lt; 0.1 pixels</td>
</tr>
<tr>
<td>Stray Light</td>
<td>&lt; 1e-4 Point Source</td>
</tr>
<tr>
<td></td>
<td>Transmission</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>256</td>
</tr>
<tr>
<td>Spectral Sampling</td>
<td>2.5, 5, 10 nm</td>
</tr>
<tr>
<td>Peak Grating Efficiency</td>
<td>88%</td>
</tr>
<tr>
<td>Slit Size</td>
<td>9.6 x .015 mm</td>
</tr>
</tbody>
</table>

### IMAGE SENSOR

<table>
<thead>
<tr>
<th></th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Sensor</td>
<td>640 x 512, with 15 um pixels</td>
</tr>
<tr>
<td>Full Well Capacity</td>
<td>Gain 0: 500,000</td>
</tr>
<tr>
<td></td>
<td>Gain 1: 80,000</td>
</tr>
<tr>
<td></td>
<td>Gain 2: 10,000</td>
</tr>
<tr>
<td>Read Noise</td>
<td>Gain 0: &lt; 83 electrons</td>
</tr>
<tr>
<td></td>
<td>Gain 1: &lt; 42 electrons</td>
</tr>
<tr>
<td></td>
<td>Gain 2: &lt; 10 electrons</td>
</tr>
<tr>
<td>Maximum Frame Rate</td>
<td>1000 frames/second</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>&gt; 50% @ 380 nm</td>
</tr>
<tr>
<td></td>
<td>80% @ 400-900 nm</td>
</tr>
<tr>
<td></td>
<td>&gt; 30% @ 1000 nm</td>
</tr>
<tr>
<td>Camera Interface</td>
<td>USB-3</td>
</tr>
<tr>
<td>Data Acquisition</td>
<td>500 MB Solid State Recorder</td>
</tr>
<tr>
<td></td>
<td>Serial Interface for GPS/INS</td>
</tr>
</tbody>
</table>

### CHAI SOFTWARE

<table>
<thead>
<tr>
<th></th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger Modes</td>
<td>Pilot, GUI, electronic, and Lat/Long triggered acquisition</td>
</tr>
<tr>
<td>Visualization</td>
<td>3-band RGB waterfall display of real-time and recorded data</td>
</tr>
<tr>
<td>Metadata</td>
<td>Temperature, pressure, and humidity</td>
</tr>
<tr>
<td>Data Format</td>
<td>RAW, ENVI BIL, or Processed</td>
</tr>
<tr>
<td>Processing</td>
<td>EXPRESSO™</td>
</tr>
</tbody>
</table>