Onboard Mission Planning for the Intelligent Payload Experiment (IPEX) Cubesat

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Background

• IPEX is a 1u Cubesat sponsored by NASA Earth Science Technology Office (ESTO)

• Goals
  – Flight validate onboard instrument data processing and product generation software for proposed HyspIRI mission (JPL)
  – Flight validate autonomous operations for instrument processing (JPL)
  – Enhance NASA outreach and University ties (Cal Poly SLO)
    • Cal Poly builds, integrates, operates IPEX cubesat
  – Manifested on Gemsat/L-39
    • October 2013 launch (May 2013 launch integration)
Cal Poly SLO CP-8 spacecraft

- 1u cubesat
- Passively stabilized
  - fixed magnets
- Cal Poly Motherboard
  - 400 MHz Atmel (no HW FPU)
  - 128 MB RAM
  - 512 MB Flash
  - Micro SD card slot (16 GB)
  - Linux OS

rapid prototype
Camera

- 5 x Omnivision OV3642
- Camera Specifications
- Focal Length (f): 4mm
- Integration Time (t_int): 67ms
- Pixel Diameter (d_pixel): 1.75um
- 3 Megapixels (2500x1600)
- FOV = ~50 degrees

Image from test balloon flight

2 of 4 Cameras
Payload CPU – Gumstix Earth Storm

- Computer on Module
- Widely used in terrestrial applications
- 800 MHz OMAP (ARM) CPU
- 512MB RAM
- 512MB Flash
- SD card slot (8GB used)
- < 1W typical power
- Runs Linux
Onboard Instrument Processing on IPEX

• IPEX will utilize the Gumstix and Atmel to:
  – Demonstrate onboard image correction and bad data rejection
    • image filtering while tumbling
  – Onboard product generation
    • Using both Omnivision 3-color data and Hyperspectral data loaded at launch
## Onboard Products/Algorithms

<table>
<thead>
<tr>
<th>Algorithm Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generalized Normalized Difference Ratio Normalized Ratios*</td>
<td>Wide range of band ratios for vegetation, burn severity, ice, ...</td>
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<tr>
<td>Thermal anomaly detection</td>
<td>Estimation of thermal output to detect volcanic activity, wild fires</td>
</tr>
<tr>
<td>Water Depth Calculation</td>
<td>Uses DEM to compute water depth</td>
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<tr>
<td>Support Vector Machine (Machine learned)*</td>
<td>Wide range of classifiers and regressions</td>
</tr>
<tr>
<td>Superpixel segmentation</td>
<td>Similar region identification</td>
</tr>
<tr>
<td>Sequential Maximum Angle Convex Cone (SMACC) / Endmember Selection</td>
<td>Spectral unmixing, material identification</td>
</tr>
<tr>
<td>FLAASH-C</td>
<td>Atmospheric correction</td>
</tr>
<tr>
<td>TextureCam*</td>
<td>General classification, decision forests</td>
</tr>
<tr>
<td>ICER*</td>
<td>Image compression</td>
</tr>
<tr>
<td>Scale Invariant Feature Transform (SIFT)*</td>
<td>Landmark Identification</td>
</tr>
<tr>
<td>Maximally Stable Extremal Regions (MSER)</td>
<td>Correspondence detection</td>
</tr>
<tr>
<td>Mixture Tuned Match Filter (MTMF)</td>
<td>Signature detection</td>
</tr>
<tr>
<td>Shapefile Generation</td>
<td>Region identification from bitmaps</td>
</tr>
</tbody>
</table>

* - routinely run
Volcanic Activity Detection

For further details see [Davies et al. 2006 RSE]
Flood Tracking

• Integrated WV-2 data (2m spatial resolution)
• Developed algorithms and workflows for water depth and volume estimation (incorporating DEM) – potential algorithms for proposed HyspIRI IPM

Reflectance of WV2 scene of Bangkok w/ flooded Don Muang Airport, acquired 11.3.2011

Surface water extent (blue) from SVM classifier using 5th degree polynomial kernel on 8 WV2 bands

Resulting water depth map calculated using SVM-classified surface water extent map and DEM. Total water volume calculated: ~27,872,000 m³; average flooded pixel depth: 0.64 m.

For further information see [Mclaren et al. 2012 SPIE, Chien et al. 2012 i-SAIRAS]
Onboard Hyperspectral Analysis

Superpixel segmentation + SMACC endmember extraction

Results from onboard EO-1 (9/2011)

For further details see [Thompson et al TGARS 2009, 2012]
IPEX/Proposed HyspIRI IPM Operations Concept

Operations Team enters request regions, products, priorities in Google Earth™ and CLASP

Pre-decisional – for Planning and Discussion Purposes Only
CLASP uses orbit information to generate time-based goal requests to ASPEN
IPEX/Proposed HyspIRI IPM Operations Concept

Other space and in-situ sensorweb assets also electronically submit image and product requests at authorized priorities

Pre-decisional – for Planning and Discussion Purposes Only
IPEX/Proposed HyspIRI IPM Operations Concept

ASPEN generates operations schedule respecting CPU, RAM, SSR, downlink volume, power, thermal,… constraints

Pre-decisional – for Planning and Discussion Purposes Only
IPEX/Proposed HyspIRI IPM Operations Concept

ASPEN schedule uplinked to IPEX or HyspIRI IPM

Pre-decisional – for Planning and Discussion Purposes Only
Onboard CASPER executes ground plan, re-planning in response to run-time variances or event detections in onboard image processing.
IPEX/Proposed HyspIRI IPM Operations Concept

Products downlinked to direct readout antenna (proposed HyspIRI IPM) or Cal Poly Groundstation (IPEX)
Autonomous Instrument Operations

• Region-based imaging and product requests input using Google Earth

• Ground:
  – CLASP planner used to collect image requests and impose region/overflight/timing of requests based on orbital ephemeris
  – ASPEN generated time-sequences schedule based on request priorities, resources, contention

• Flight:
  – CASPER modified ground schedule based on flight resources and onboard requests due to onboard image analysis
CLASP

- Schedule planner for spacecraft spatial coverage
  - Been used for DESDynI mission concept studies
  - Outputs a nominal plan under some operational constraints, e.g. downlink bandwidth
  - Can output an ASPEN compatible schedule for further refinement
- On right, a sample output with 120° inclination orbit (Gemsat L-39)

Predecisional – for Planning and Discussion Purposes Only
Autonomous Operations

• Baseline Schedule created on ground using ASPEN
  – Observation keep-in window
    – Use of Gumstix or cameras hampers uplink to spacecraft
  – Eclipse schedule
  – Observation Activities + processing
  – Ground initiated processing experiments

• Constraints:
  – CPU usage
  – Data storage: raw images, processed images, summary products < flash storage capacity (e.g. 4GB)
  – Energy capacity of battery: ~50 Whr
  – Solar generation: <~1.5 Watt
  – CLASP capable of modeling above constraints, ground ASPEN used for flight CASPER compatibility
CASPER Onboard Safety Analysis

- Informal methods safety analysis of known risks to spacecraft; here we focus on those enforced by CASPER

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Example Risk</th>
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<tbody>
<tr>
<td>Power (14,3)</td>
<td>Battery SOC run too low</td>
</tr>
<tr>
<td></td>
<td>Solar cell failure</td>
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<tr>
<td></td>
<td>Battery degradation failure</td>
</tr>
<tr>
<td>Pointing (4,1)</td>
<td>Spin rate too high</td>
</tr>
<tr>
<td>Instrument (6,4)</td>
<td>Image acquisition flooding</td>
</tr>
<tr>
<td>Software (23,13)</td>
<td>Hanging process, blocks other processes</td>
</tr>
<tr>
<td></td>
<td>System memory exhaustion</td>
</tr>
<tr>
<td></td>
<td>CDH CPU oversubscription</td>
</tr>
<tr>
<td>SD Card (3,1)</td>
<td>Write beyond SD card capacity</td>
</tr>
<tr>
<td>Communications (6,1)</td>
<td>Payload card noise interferes with uplink</td>
</tr>
</tbody>
</table>
Autonomous Operations

- Ground Contact
- Atmel image proc
- Obs + proc act
- Solar power gen
- Atmel CPU in use
- Battery Charge
- SSR storage
- Raw SSR storage
Autonomous Operations for Intelligent Payload Module

- HyspIRI Mission concept is under study which proposes a VSWIR hyperspectral imager and TIR Thermal infra-red imager
- This HyspIRI concept includes a heritage Direct Broadcast concept Intelligent Payload Module which would process the ~800 x 10^6 bits/second raw data stream into ~10 x 10^6 bits/second direct broadcast data stream
- IPEX will demonstrate automated planning and processing of the data as maturation of the prototype HyspIRI IPM operations system
  - Users specify regions of interest, products, and priorities in Google Earth™
  - System automatically creates priority based plans for onboard processing and downlink

Pre-decisional – for Planning and Discussion Purposes Only
Proposed HyspIRI Instrument Swaths

4 x 112.5.5 km wide – TIR only

4 x 37.5 km wide – VSWIR + TIR

Pre-decisional – for Planning and Discussion Purposes Only
Proposed HyspIRI IPM Sample Plans

Pre-decisional – for Planning and Discussion Purposes Only
IPEX Balloon Unit Flight

- Flown 28 July 2012, peak altitude 104,000 feet above sea level
- Flown 09 December 2012, peak altitude 88,000 feet above sea level
- Balloon unit included two CPU “CP top hat” units, each with Atmel CPU, SD card, 4 cameras
- CASPER installed on one “top hat” and planned over 300 activities corresponding to over 3000 commands
- Despite one SD card/file system failure, acquired over 1000 images
- See http://scienceandtechnology.jpl.nasa.gov
Conclusions

• The IPEX Cubesat will Flight Demonstrate Autonomous Payload Operations for the proposed HyspIRI mission Intelligent Payload Module
  – Onboard Image Processing and Product Generation
  – Onboard Mission planning for dynamic processing and resource management
  – Ground-based automated planning for processing request generation and management
  – IPEX currently manifested to launch 10/13 on GEMSAT L-39, with several year projected mission lifetime