A Distributed Command and Data Handling Architecture for KYSat–2

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- Partnerships: COSMIAC, Kentucky Space
Overview

- Space Systems Lab
- K-Bus Distributed Communications and Power
- KySat-2 Overview
- Imaging Payload
A Distributed Command and Data Handling Architecture for KYSat-2

Detected Stars in first frame
Detected Stars in second frame
Paired stars using RANSAC

New NanoRacks/CubeLab Standard on the ISS, July 2010

KYSat-1 2006
KYSat-2 2013
PRINTSat and RAMPART 2012
First CubeSats Ejected into Sub-Orbital Space, March 2010

High Altitude Balloons (Background Image)
First Flight, Composite Super Loki, December 2007
Garvey P-12A
Kentucky–Bus (K–Bus)

- Develop a standard bus for communications for small spacecraft
- Develop a standard bus for power for small spacecraft
- Combine these into K–Bus
  - Communications leverage plug–and–play SPA SDM–Lite infrastructure
  - Modular plug–and–play power system
K-Bus

Data Bus Interface

Power Bus Interface

Solar Array Module

Radio

Other Subsystems

Battery Module

Command & Data Handling

Payload
K–Bus Communications

- SPA–based SDM–Lite developed by COSMIAC and the SSL
  - Utilizes I²C as communication layer between SDM and ASIM
  - Implemented on COSMIAC’s Trailblazer, KySat–2, and on the CubeLab Bus on the ISS
K–Bus Power Features

- Modular, scalable distributed EPS technology
- Point of Load Regulation
  - Subsystems receive battery power, provide regulation themselves
- Incorporate DET as solar array interface
- Over voltage, over discharge, under voltage battery protection
- Battery, solar panel, and payload telemetry reporting
KySat–2 Mission

- Goals:
  - Distributed processing architecture
  - Educational/Public Outreach through photos and sensor data for K–12
  - Stellar Gyroscope Payload
Board Stackup

- Deployment Board
- Phasing Board
- Radio
- Imaging System
- C&DH
- Battery Holding
- EPS
- Camera Structure
KySat-2 C&DH

- Custom Command and Data Handling system created by the Space Systems Lab
- Integrates mission and interface processors, storage, fault tolerance
  - Command API
  - Data exchange API
Development Process

- Development board (below)

- FlatSat under test (above)
KySat–2 Payload

- Infer attitude change from successive star images
- Take star-field image sets
  - With timestamps (to tell rate)
  - With MEMS gyro rate data in between (to compare image estimate with propagation)
- To download more data, star coordinates and magnitude measurements can be downloaded as text files
Stellar Gyroscope Examples
Imager Specifications

- CMOS Sensor with S-Mount Lens
- Single board Linux computer running OpenCV image processing library
- Gain and exposure control

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Beagle Board running Angstrom Linux</td>
</tr>
<tr>
<td>Sensor</td>
<td>Aptina MT9P031 5 MP CMOS detector</td>
</tr>
<tr>
<td>Optics</td>
<td>16 mm focal length, Aperture F/1.2</td>
</tr>
<tr>
<td>Field of View</td>
<td>15° by 20.2°</td>
</tr>
<tr>
<td>ADC Resolution</td>
<td>12 bits</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>2.2 x 2.2 µm</td>
</tr>
</tbody>
</table>
Summary

- K-Bus is combination of modular, plug-and-play data and power bus for small spacecraft
- KYSat-2 has a distributed command system and stellar gyroscope payload
- Papers:
  - Providing a Persistent Space Plug-and-Play Avionics Network on the International Space Station
    - [http://uknowledge.uky.edu/ece_etds/16/](http://uknowledge.uky.edu/ece_etds/16/)
Thank you

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Backup Slides
Direct Energy Transfer

Table 6: Overall Solar Cell to Battery Efficiencies

<table>
<thead>
<tr>
<th>Solar Interface</th>
<th>No BCR</th>
<th>With Expected BCR Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spin 1°/s, No Radiation</td>
<td>Spin 20°/s, No Radiation</td>
</tr>
<tr>
<td>Fractional</td>
<td>99.1%</td>
<td>84.2%</td>
</tr>
<tr>
<td>P&amp;O</td>
<td>98.6%</td>
<td>83.8%</td>
</tr>
<tr>
<td>dP/dV</td>
<td>98.9%</td>
<td>84.1%</td>
</tr>
<tr>
<td>Fixed</td>
<td>95.7%</td>
<td>81.3%</td>
</tr>
<tr>
<td>TC Fixed</td>
<td>99.2%</td>
<td>84.3%</td>
</tr>
<tr>
<td>DET (No BCR)</td>
<td>86.5%</td>
<td>86.5%</td>
</tr>
</tbody>
</table>

- **Fractional**: operating at a set fraction of the open-circuit voltage
- **P&O**: Perturb and Observe
- **dP/dV**: Seeking maximum power by varying operating voltage
- **Fixed**: Fixed operating voltage
- **TC Fixed**: Temperature-compensated fixed operating voltage
- **DET**: Direct Energy Transfer

Concept of Stellar Gyroscope

Observe the motion of stars in camera’s field of view to infer changes in satellite’s attitude.

- Measures relative attitude between exposures with common stars
- Tolerates large amount of noise, allowing low cost assembly and small form factor
Star Detection

- Convolution filter, experimented with several mask sizes and shapes.
  - Minimizing false positives
  - Extracting dim stars
- Best so far: Sinc function
Centroiding, aka Expected Value

\[ E(x) = \sum x \cdot f_x(x) \]

\[ f_x(x) = \sum_y f_{xy}(x,y) \]
Solving the Relative Attitude Problem

- Using the Direction-Cosine-Matrix (DCM) notation, the attitude change between two frames satisfies:
  \[ \overrightarrow{v^b} = C^{ba} \overrightarrow{v^a} \]

- The goal is to find the rotation matrix \( C^{ba} \) that defines the rotation between frame \( a \) and frame \( b \), by minimizing the cost function:
  \[
  J(C^{ba}) = \sum_{k=1}^{L} w_k \left| v^b_k - C^{ba} v^a_k \right|^2
  \]

- Given at least two vector measurements (two stars before-and-after), The Q-Method is used to find the analytically optimal relative attitude estimate.
RANSAC: iterative method to estimate parameters of a mathematical model from a set of observed data which is contaminated a large number of outliers that do not fit the model.

The steps of RANSAC can be summarized as

- **Hypothesize**: A hypothesis rotation is based on MEMS rate information, or calculated using randomly selected star pairs across frames.
- **Test**: The estimated rotation matrix is tested against all the stars in the two frames. Stars that show consensus are counted towards the Consensus Set (CS).
- **Iterate**: RANSAC iterates between the above two steps until a random hypothesis finds “enough” consensus to some selected threshold.
Dataset from Raven Run Area

www.sky-map.org image of same region
Assuming perfect attitude knowledge before entering eclipse

MEMS rate gyro: 50Hz, $\pm 80^\circ$/second, 12-bit ADC, Noise 0.1 $^\circ$/second RMS

Attitude knowledge error increases up to 5 $^\circ$ in the first 5 minutes and more than 10 $^\circ$ after 35 minutes.
MEMS assisted by Stellar Gyroscope

- Assuming perfect attitude knowledge before entering eclipse
- Stellar gyro generates attitude estimates ($\sigma = 0.1^\circ$), at 15 second increments, relative to the first photo taken at the beginning of eclipse.
- Drift is maintained below $1^\circ$