Hyperspectral Cubesat Constellation for Rapid Natural Hazard Response

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Abstract
Earth Observing 1 (EO-1) satellite has an imaging spectrometer (hyperspectral) instrument called Hyperion. The satellite is able to image any spot on Earth in the nadir looking direction every 16 days. With slewing of the satellite and allowing for up to a 23 degree view angle, any spot on the Earth can be imaged approximately every 2 to 3 days. EO-1 has been used to track many natural hazards such as wildfires, volcanoes and floods. An enhanced capability that is sought is the ability to image natural hazards in a daily time series for space based imaging spectrometers. The Hyperion can not provide this capability on EO-1 with the present polar orbit. However, a constellation of cubesats, each with the same imaging spectrometer, positioned strategically in the same orbit, can be used to provide daily coverage, cost-effectively.

Overview
New onboard processing capability is enabling more rapid response for satellites with imaging spectrometers. Figure 1 depicts a Field Programmable Gate Array (FPGA) based onboard processing that performs a data processing chain on raw data from an imaging spectrometer and is able to download the finished products directly to the user. As an example, using a CHREC Space Processor (CSP) which is based on the Zynq chip (2 Arm processors and FPGA circuits) can provide real-time onboard processing support of the raw data at rates of 1 Gbps. The cubesats with the instruments can be built for under $1 million each.

Concept of Operations
In this concept of operations, a number of cubesats are placed in the same orbit so as the earth rotates under the constellation, at least one of the satellites will have the target in its view. Figure 2 shows the basic architecture components of the note. That in this architecture, there are two modes to communicate to the cubesats. The first is via S-band to the ground network at about 2 Mbps to handle the higher level data products. The second is 1 kbps S-band to TDRSS via the Space Network to enable total coverage for commanding and basic telemetry for health and safety of the cubesats.
This model of operations emulates the EO-1 concept of operations whereby there is a high speed data downlink and low rate for command and telemetry. In the case of EO-1, X-band is used at 100 Mbps downlink rate for the instrument data. But due to power limitation, the cubesats use S-band at 2 Mbps fro their high data downlink channel to get total power constraints. The low rate for EO-1 is either to the Ground Network at 32 kbps or 8 kbps to TDRSS via Space Network. In the case of the cubesats, it would be 1 kbps to TDRSS via Space Network to stay within the power constraints of the smaller antennas and the limited power capacity.

Constellation Coverage
The assumption is that a number of cubesats are placed somewhere between a space station and a high polar orbit at an elevation of approximately 400 km. The cubesat that was designed for this effort call for a 30 meter pixel resolution with a 640 pixel swath using a push broom imaging spectrometer. Each image is approximately 10 km wide. The circumference of the earth is approximately 40000 km. So the question is, what is the relationship with the required slew angle to get total coverage. Table 1 below shows how many satellites are required for three allowable slew angles to obtain total daily coverage:

<table>
<thead>
<tr>
<th>Component Name</th>
<th>Vendor</th>
<th>Dimensions</th>
<th>Mass</th>
<th>Count</th>
<th>Cost</th>
<th>TRL</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Wh Battery</td>
<td>Clyde Space</td>
<td>95.885mm x 90.170 mm x 20.440mm</td>
<td>256g</td>
<td>1</td>
<td>$3,850</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>6U CubeSat Side Solar Panel</td>
<td>Clyde Space</td>
<td>70x50x25 mm</td>
<td>148g</td>
<td>1</td>
<td>$13,500</td>
<td>9</td>
<td>39W</td>
</tr>
<tr>
<td>3U 2-Sided Double Deployed Solar Panel</td>
<td>Clyde Space</td>
<td>70x50x25 mm</td>
<td>148g</td>
<td>1</td>
<td>$13,500</td>
<td>9</td>
<td>39W</td>
</tr>
<tr>
<td>SCR-102 S-Band radio</td>
<td>Innolight</td>
<td>(82 x 82 x 35)</td>
<td>290g</td>
<td>1</td>
<td>$80,000</td>
<td>9</td>
<td>8W</td>
</tr>
<tr>
<td>3G Flex EPS (Electrical Power System)</td>
<td>Clyde Space</td>
<td>(90.80 x 85.08x14.95) mm</td>
<td>148g</td>
<td>1</td>
<td>$13,500</td>
<td>9</td>
<td>39W</td>
</tr>
<tr>
<td>Nano-Hyperspec</td>
<td>Headwall</td>
<td>76.2mm x 76.2mm x 119.92mm</td>
<td>.6kg</td>
<td>1</td>
<td>$200,000</td>
<td>9/Aerial, 6/Space</td>
<td>10W</td>
</tr>
<tr>
<td>KACT Attitude Determination System</td>
<td>Blue Canyon Tech</td>
<td>10 x 10 x 5 cm</td>
<td>850g</td>
<td>1</td>
<td>$250,000</td>
<td>9</td>
<td>Max 2.83W</td>
</tr>
<tr>
<td>SGR-05U Space GPS Receiver (antenna included)</td>
<td>Surrey Satellite Technologies US LLC</td>
<td>70x46x12 mm</td>
<td>20g</td>
<td>1</td>
<td>$26,300</td>
<td>9</td>
<td>0.8W</td>
</tr>
<tr>
<td>CHREC Space Processor</td>
<td>Space Micro</td>
<td>88 x 89 x 15mm</td>
<td>72g</td>
<td>2</td>
<td>$30,000</td>
<td>9</td>
<td>2.5W</td>
</tr>
<tr>
<td>GU Box</td>
<td></td>
<td>88 x 89 x 15mm</td>
<td>72g</td>
<td>2</td>
<td>$30,000</td>
<td>9</td>
<td>2.5W</td>
</tr>
</tbody>
</table>

Table 1 shows some tradeoffs between allowable view angle and the number of cubesats needed in a constellation to achieve total daily coverage.

CONCLUSION
The main goal of this effort was to find a cost-effective way to serve the disaster community with daily repeat measurements with space based imaging spectrometers. There are numerous ways to use spectral measurements to enhance responsiveness to disaster scenarios. Off the shelf components for cubesats offer a way to build a cost-effective constellation.