Overview of Aoba VELOX-IV Missions; Pulsed Plasma Thruster Attitude and Orbit Control and Earth-rim Night Image Capture for A Future Lunar Mission

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A two-unit CubeSat developed in collaboration with Nanyang Technological University, Singapore and Kyushu Institute of Technology, Japan.

- Technology demonstration satellite for a future lunar mission in LEO.
- AV4 will be launched by JAXA in 2018 (to be confirmed), and AV4 mission will be supported by a ground station network placed in Japan, Taiwan, Singapore and Mongolia.
Aoba VELOX-IV

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Technology demonstration satellite in LEO for a future lunar mission.

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Technology demonstration satellite for a future lunar mission in LEO.

AV4 will be launched by JAXA in 2018 (to be confirmed), and AV4 mission will be supported by a ground station network placed in Japan, Taiwan, Singapore and Mongolia.
• Detection of the lunar horizon glow (LHG).
  • **First spotted in 1966 and 1968** by on-board cameras on **Surveyor missions**.
  • Apollo astronauts saw it and made drawings from their observations.
  • The **Lunokhod-II astrophotometer detected a brighter twilight** as expected.
  • **High-varying phenomena** different levels of luminosity reported from further lunar missions
  • LHG causes are still investigated

NASA photos, Criswell, 1973; Rennilson and Criswell, 1974; Colwell et.al., 2007
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Aoba VELOX-IV and the future lunar mission

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Stubbs, T. J. et.al. 2007. A sketch by Apollo 17 astronaut Eugene Cernan. Coronal and Zodiacal Glow in Red Line (CZG), Lunar Horizon Glow (LHG) in blue line, crepuscular rays in green lines formed by shadowing and scattered light.
Aoba VELOX-IV as technology demonstration satellite

- LHG different intensity levels:
  - Apollo: 0.2-20 lux
  - Surveyor: 60-2600 lux

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- Choose of a low-light camera

Stubbs, T. J. et.al. 2007.

NASA photos, Criswell, 1973; Rennilson and Criswell, 1974; Colwell et.al., 2007

CAD Drawing of the Camera Module (Kyutech).
Aoba VELOX-IV as technology demonstration satellite

- Irregular lunar gravity field, orbit maintenance required to extend its mission lifetime

Mission lifetime analysis without orbit maintenance (Kyutech)
Aoba VELOX-IV as technology demonstration satellite

- Irregular lunar gravity field, orbit maintenance required to extend its mission lifetime

- Pulsed plasma thrusters developed by NTU
- AOCS software developed by Kyutech

Mission lifetime analysis without orbit maintenance (Kyutech)

Satellite crashes on Moon surface within 40 days

CAD Drawing of the PPT (NTU).
The objective of camera payload can be given as:

Earth Mission:
- Earth-rim
- Night view and aurora
- Horizon detection

Payload requires:
- a small size and mass
- a circuitry to compress raw images to JPEG format
- COTS camera modules
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**Earth Mission:**
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- Night view and aurora
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**Lunar Mission:**
- LHG

Payload requires:
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**TARGET:**
LUNAR ORBIT MISSION

**PURPOSE:**
TECHNOLOGY DEMONSTRATION IN LEO ORBIT
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Payload requires:
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### Specifications vs. Requirements

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>&lt; 0.2 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>&lt; 0.1U</td>
</tr>
<tr>
<td>Maximum Resolution</td>
<td>VGA</td>
</tr>
<tr>
<td>Sensor Type</td>
<td>CMOS or CCD</td>
</tr>
<tr>
<td>Field of View</td>
<td>&gt;40°</td>
</tr>
<tr>
<td>Minimum Luminosity</td>
<td>0.015 Lux</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>3.0 V/Lux-sec and higher</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>0.033 sec</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-10 to 50 °C</td>
</tr>
<tr>
<td>Interfaces</td>
<td>UART, SPI, I2C</td>
</tr>
<tr>
<td>Possible Secondary Operation</td>
<td>Horizon Detection</td>
</tr>
</tbody>
</table>
**AOCS requirements**

- Pointing towards horizon
  - Images from Sunset
  - Images from Earth rim in night side
- Orbit maintenance capabilities
  - Demonstrate orbit maintenance capabilities
  - About 60m/s as $\Delta v$ orbiting maneuvering.
- Momentum dumping by PPT
  - Demonstrate momentum dumping capabilities
  - 0.0001Nms angular momentum reduction via PPT
- Desaturation of reaction wheels by PPT
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• Desaturation of reaction wheels by PPT
Camera system overview

A high number of COTS cameras has been considered.
• **the interface and light sensitivity requirements** eliminated most of the candidates.
• **the power consumption and size requirements** were effective for the selection as well.
The payload has been determined as C329BW camera module.

<table>
<thead>
<tr>
<th>Camera Specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Camera</strong></td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td>Sensor Type</td>
</tr>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>Power Consumption</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Interface</td>
</tr>
<tr>
<td>Sensor S/N Ratio</td>
</tr>
<tr>
<td>Dynamic Range</td>
</tr>
</tbody>
</table>

CAD Drawing of the Camera Module (Kyutech).
AOCS overview

Due to mass restrictions, minimum required hardware for two-axis stabilized satellite will be used.

AOCS software will be embedded into a DSP based on-board computer.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sun</td>
<td>Six SLCD-71N8 coarse sun sensors distributed along the satellite body. 60° half angle.</td>
</tr>
<tr>
<td>sensors</td>
<td></td>
</tr>
<tr>
<td>Fine sun</td>
<td>Two GOM Space NanoSense FSS-4 fine sun sensors placed in -z and -x axis. 60° half angle.</td>
</tr>
<tr>
<td>sensors</td>
<td></td>
</tr>
<tr>
<td>Gyroscope</td>
<td>One three-axis gyroscope ICG20330 from inventsense, with a noise of 5 mdps/√Hz.</td>
</tr>
<tr>
<td>Reaction Wheels</td>
<td>Three reaction wheels aligned with x, y and z axis, angular momentum 2gm2s-1 at 4800 rpm.</td>
</tr>
<tr>
<td>Pulsed Plasma</td>
<td>Four heads placed in +z satellite face, operation frequency at 1 Hz. 25.20322 μNs as impulse bit and 60[m/sec] as maximum Δv.</td>
</tr>
</tbody>
</table>

![AOCS diagram]
Image acquisition

Time period: less than 2 sec
- 25 msec SYNC x 2
- 33 msec Transfer
- 33 msec Exposure
- Less than 1 sec for compression + ACK

Software Size: ~10 KB
Image Size: ~ 307 KB (Raw) / 30 KB (JPEG)

Horizon Detection Algorithm

[Diagram showing the horizon detection algorithm with steps involving OBC, AOCs, image capture, noise filtering, horizon edges determination, elimination of anomalies, attitude information, and edge detection and curve fitting.]
Camera system software

Horizon Detection Algorithm

Payload
- Image Capture
- Noise Filtering
- Horizon Edges Determination
- Elimination of Anomalies (Stars, Landscape, etc.)
- Attitude Information
- Edge Detection and Curve Fitting

Horizon Information is required

OBC

AOCS

Sample images taken from Google.
# AOCS software

## Operation modes and features

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Features</th>
<th>Hardware required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detumble mode</strong></td>
<td>Reduction of angular rate via reaction wheels</td>
<td>RWs, gyroscope</td>
</tr>
<tr>
<td><strong>Sun-pointing mode</strong></td>
<td>The solar paddles alignment to the sun for optimal solar energy collection.</td>
<td>Coarse sun sensors, RWs, gyroscope</td>
</tr>
<tr>
<td><strong>Initialization mode</strong></td>
<td>Initialization of orbit propagator and EKF. Solar paddles aim to the Sun by z axis angle control.</td>
<td>Coarse and fine sun sensors, gyroscope, RWs</td>
</tr>
<tr>
<td><strong>Science mode</strong></td>
<td>Satellite control its attitude to the target. Orbit maintenance and horizon observation.</td>
<td>Coarse and fine sun sensors, gyroscope, RWs and PPT</td>
</tr>
<tr>
<td><strong>Momentum dumping mode</strong></td>
<td>Desaturation of RW via PPT.</td>
<td>Gyroscope, RWs and PPT</td>
</tr>
</tbody>
</table>

![AOCS software flowchart](image-url)
Conclusions

• Camera module was selected for the observation of low-light images from either Earth or Moon.

• Regarding AOCS, pointing towards horizon and orbit maintenance are the main objectives to be met in both Earth and Moon orbit cases.
  • A reliable orbit propagation and attitude determination algorithm is required to be implemented into AOCS software.
  • PPTs can be used for both orbit maintenance and desaturation of reaction wheels.

• To improve the reliability of AOCS, the camera module can serve as horizon sensor to increase the accuracy of attitude knowledge with the development of horizon detection algorithms.
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Thank you!