Tunable Light-guide Image Processing Snapshot Spectrometer (TuLIPSS) for Earth and Moon Observations.

02-28-2018

T. S. Tkaczyk¹, D. Alexander², J. C. Luvall³, Ye Wang¹, J. G. Dwight¹, M. E. Pawlowski¹, B. Howell⁴ and P. Tatum³, R.-I. Stoian¹, Shuna Cheng¹, Antoun Daou²

¹ Department of Bioengineering, Rice University 6100 Main Street, Houston, Texas 77005, tkaczyk@rice.edu.
² Department of Physics and Astronomy, Rice University 6100 Main Street, Houston, Texas 77005, dalex@rice.edu.
³ NSSTC, NASA Marshall Space Flight Center, 320 Sparkman Dr., Huntsville, AL 35805, jluvall@nasa.gov
⁴ USRA STI, 320 Sparkman Dr., Huntsville, AL 35805, @protonmail.com
**FUNCTION STATEMENT**
A tunable light-guide image processing snapshot spectrometer (TuLIPSS) for hyperspectral Earth Science Research and Observation - TuLIPSS will be capable of acquiring instantaneous images across the visible and near-IR, within a flexible spatial/spectral resolution trade space. Can be applied to Earth and Lunar Observation (EO and LO).

**WHY IS THE GATEWAY THE OPTIMAL FACILITY FOR THIS INSTRUMENT/RESEARCH?**
The Gateway’s primary advantages include “
- “whole earth” monitoring (lightning distribution and spectrum, atmospheric chemistry),
- hyperspectral lunar surface remote sensing (Lunar Impact Flash Monitoring, Exosphere Evolution – K, Na; surface mineral and water mapping),
- test platform for high capability, multi-functional, low resource instrument for Mars (both using external and internal platforms – allows changing applications in single instrument, station safety and performance – outgassing, plume etc. and crew health monitoring).

- Single instrument capable of multiple applications utilizing external platform for EO and LO and internal for monitoring crew health
- Tunability allows lower data content as it optimizes spectral-spatial acquisition for specific applications
  - tunable adjustment of spatial and spectral resolution, and flexible selection of target wavelengths and band passes (spatial dimensions at this point 100x100 through 400x400 while spectral sampling varies between 30 and 250)
- Improvement of quality of data / extending dynamic range through snapshot imaging of overlapping scenes and adjusting sensitivity of ROIs on FPA
  - processing of overlapping regions obtained in snapshot
  - adjustment of dynamic range within ROI
- Spectral coverage for 400nm – 1700nm
### Basic Instrument Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>INSTRUMENT ESTIMATE &amp; ANY COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MASS (KG)</td>
<td>Depends on implementation: for limited tuning hardware &lt; 5 kg; for complete tuning functionality and dual spectral detection &lt; 15kg</td>
</tr>
<tr>
<td>VOLUME (M)</td>
<td>Depends on implementation: for limited tuning hardware &lt; 6U; for complete tuning functionality and dual spectral detection &lt; 20U</td>
</tr>
<tr>
<td>POWER (W)</td>
<td>TBD</td>
</tr>
<tr>
<td>THERMAL REQUIREMENTS</td>
<td>TBD</td>
</tr>
<tr>
<td>DAILY DATA VOLUME</td>
<td>Application dependent. Current design provides cube in size of 10,000,000 values of 12bit data. The system is capable of acquiring up to 100 data-cubes / sec (this is though a capability rather than requirement)</td>
</tr>
<tr>
<td>CURRENT TRL</td>
<td>In transition from 3 to 4</td>
</tr>
<tr>
<td>WAG COST &amp; BASIS</td>
<td>TBD – depending on tunability level, cost is currently driven by FPAs and tuning control</td>
</tr>
<tr>
<td>DURATION OF EXPERIMENT</td>
<td>The system is a snapshot modality enabling range of applications – duration will be application dependent</td>
</tr>
<tr>
<td>OTHER PARAMETERS</td>
<td></td>
</tr>
</tbody>
</table>
### Instrument Gateway Usage

<table>
<thead>
<tr>
<th>USAGE</th>
<th>INSTRUMENT REQUIREMENTS &amp; COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORBIT CONSIDERATIONS</td>
<td>Application dependent</td>
</tr>
<tr>
<td>FIELD OF VIEW REQUIREMENTS</td>
<td>Application dependent</td>
</tr>
<tr>
<td>REQUIRES USE OF AIRLOCK</td>
<td>Application dependent</td>
</tr>
<tr>
<td>CREW INTERACTION REQUIRED?</td>
<td>Possible for in-station tests, not required. In case of crew health monitoring interaction will be necessary.</td>
</tr>
<tr>
<td>WILL ASTRONAUT PRESENCE BE DISRUPTIVE?</td>
<td>No</td>
</tr>
<tr>
<td>DOES THE INSTRUMENT PRESENT A RISK TO THE CREW</td>
<td>No</td>
</tr>
<tr>
<td>OTHER CONSUMABLES REQUIRED</td>
<td>NA</td>
</tr>
<tr>
<td>SPECIAL SAMPLE HANDLING REQUIREMENTS</td>
<td>NA</td>
</tr>
<tr>
<td>NEED FOR TELEROBOTICS?</td>
<td>The instrument will have internal tuning capability</td>
</tr>
<tr>
<td>OTHER REQUIREMENTS OF THE GATEWAY?</td>
<td>NA</td>
</tr>
</tbody>
</table>
References and Status of Work in this Field


• Materials outgassing https://outgassing.nasa.gov

• NASA’s Long Duration Exposure Facility, or LDEF. https://curator.jsc.nasa.gov/mic/ldef/index.cfm

Snapshot Multi / Hyperspectral Systems based on Image Re-organization

Ye Wang et al, OPTICAL ENGINEERING, Volume: 56  Issue: 8. AUG 2017

Liang Gao et al, 20 July 2009 / Vol. 17, No. 15 / OPTICS EXPRESS


- Ye Wang et al, OPTICAL ENGINEERING, Volume: 56  Issue: 8. AUG 2017
- Journal of Cell Science, JOCES/2012/108258
- Journal of Biomedical Optics Letters, August 2012 • Vol. 17(8), p.080508-1
- Optical Engineering 51(11), (November 2012)
- Optical Engineering 51(4), 043203 (April 2012)
- JOURNAL OF MICROSCOPY Volume: 246  Issue: 2 Pages: 113-123, MAY 2012
- Journal of Biomedical Optics, 16(05), 056005, May 2011
Mirror Based – compact image slicing/mapping system


Mirror Based – compact image slicing/mapping system – cont.

- A cost effective platform for environmental sensing applications that include monitoring water quality, land use, air pollution, vegetation and agriculture.
- Small size, power, and weight of payloads allows for a wider range of applications, incorporation of additional instrumentation or the augmentation of flight parameters such as altitude, distance and duration.
- System demonstrates high light-throughput.
- Hyperspectral datacubes can be acquired at 1/500 sec to 1/100 sec, eliminating motion artifacts
- Applications include monitoring plant pigmentation, vegetation state, leak detection at petrochemical plants, and urban sustainability, lightning etc.

J.Dwight et. al, poster presentation at HyspIRI Workshop, Caltech, October 2017
Mirror Based – compact image slicing/mapping system – cont.

Lenslet array tunable snapshot imaging spectrometer (LATIS)

Fiber based spectrometer – proof of concept

Ye Wang, Michal E. Pawlowski, Tomasz S. Tkaczyk, "High spatial sampling light-guide snapshot spectrometer", OPTICAL ENGINEERING, Volume: 56 Issue: 8 AUG 2017
Current TuLIPSS Activities/Improvements

- Decreasing bundle dimensions (below 1 inch input) – smaller individual fiber diameter (10 microns and below)
- Optimizing throughput – fiber NA and coupling (lenslet array)
- Increasing spatial sampling (targeted 400x400)
- Elastic tuning (1-2 second mode switching) of fiber distance
  - Mechanical actuators
  - Magnetic
  - Pneumatic
- Dispersion and bandwidth tuning (selection of sub-bands and spectral sampling)
- ROI dynamic range tuning
First view of Earth Taken by a Spacecraft
Lunar Orbiter I, 16th orbit, Aug. 23, 1966

Deep Space Gateway
TuLIPSS Observations
✓ Earth
✓ Lunar
✓ Station
✓ Earth-Lunar
Earth Observations

The image is composite made from a series of images taken by the **Lunar Reconnaissance Orbiter Camera** (LROC) on October 12, 2015. “Earthrise”

Apollo 8, the first manned mission to the moon, entered lunar orbit on Christmas Eve, Dec. 24, 1968.

Near Rectilinear Orbit (NRO)
6-8 days
2,000 to 75,000 km Roughly polar
Earth ~ 10x geo distance

**L1 and Distant Retrograde Orbit better suited for earth obs.**

Ability to change orbits impacts types of possible observations, ie spectral, temporal & spatial domains

Whitley and Martinez 2015

Earth Observations

**Lightning**

**Harmful Algal Blooms/Water quality**

**Volcanic activity**

**Terrestrial Ecosystems (400-2400 nm)**

**Agriculture**

**Atmospheric Chemistry/Air Quality**
Earth Observations - Lightning

Lightning Observation

600-950 nm
Detection ~ 500 frames/sec
10 km resolution
5-10 nm Spectral bandwidth

Christian et al., 1989
Earth Observations – Water Quality

HICO Image of Lake Erie 2nd largest bloom year

HICO Image of Lake Erie 2nd largest bloom year

400-700 nm
Imaged 1x per day
100m spatial resolution
5 nm bandwidth

True Color (OSU, not reprojected)

HyspIRI measurements - Designated 2017 Decadal Survey

Ortiz et al., 2017
Reflectance Spectra from Various Algal Groups

1st derivative

Provides information on different pigments and thus algal and cyanophyte composition

First derivative of reflectance spectra for various algal groups and mixtures

Wavelength (nm)

First Derivative, dR/dL

Ortiz et al., (HyspIRI 2015)
Lunar Observations

Lunar Impact Flash Monitoring – 400-900 nm
Continuous monitoring 10 km res ~ 5-10 nm bandwidth

Surface Mineral Mapping
500-1000 nm, 900-1700 nm, 1700-2600 nm
Specific targets of interest 15 nm bandwidth 80 m Spatial Res

Lunar Exosphere Evolution (Na & K) (SELENE)
Periodic imaging 589.3 nm, 3.5 nm BW 630 nm, 2 nm BW
Lunar Disk Kagitani et al., 2010

This false-color image composed of 15 images taken through three color filters by NASA’s Galileo spacecraft, as it passed through the Earth-Moon system on Dec. 8, 1992

Suggs et al, 2007

Kagitani et al., 2010
The International Space Station, with a crew of six onboard, is seen in silhouette as it transits the moon at roughly five miles per second on Tuesday, Jan. 3.

Materials Exposure Monitoring (LADEE)
230 to 1700 nm
Imaged as needed
Macro to microscopic
1 nm bandwidth
https://curator.jsc.nasa.gov/mic/ldef/index.cfm

Material Out Gassing
230 to 1700 nm
Imaged as needed
Macro to microscopic
1 nm bandwidth
https://outgassing.nasa.gov

Rocket Plume Emission Analysis
400 to 1700 nm
Imaged as needed
TBD
5 nm bandwidth
Hudson et al., 1998
Geocorona Monitoring

300 - 400 nm & 10 - 121 nm
Periodic Monitoring
Earth Disk & surrounding space ~ 600,000 km
10 nm

Fig. 1, Kameda et al., 2017
SUMMARY on TuLIPSS for Gateway usage and benefits

System main features
- Snapshot operation
- Capable of multiple applications for external platform for EO and IO and internal for monitoring crew health
- Tunability to lower data content – system optimizes spectral-spatial acquisition for specific applications
- Improvement of quality of data / extending dynamic range through snapshot imaging of overlapping scenes and adjusting sensitivity of ROIs on FPA
- Spectral coverage for 400nm – 1700nm and its subsets

TuLIPSS in context of Gateway
- “whole earth" monitoring (lightning distribution and spectrum, atmospheric chemistry),
- hyperspectral lunar surface remote sensing
- test platform for high capability, multi-functional, low resource instrument for Mars (both using external and internal platforms – allows changing applications in single instrument, station safety and performance – outgassing, plume etc. and crew health monitoring).
Acknowledgment:

Tunable Light-guide Image Processing Snapshot Spectrometer - TuLIPSS system is being developed through a NASA ESTO Instrument Incubator Program NNH16ZDA001N-IIP at Rice University (Tkaczyk, PI; Alexander Science-PI) with support of Marshall Space Flight Center and USRA