Imaging systems for high altitude platforms

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European missions for Aquatic Earth Observation

Copernicus Sentinel 3 OLCI: global observer


European missions for Aquatic Earth Observation
Copernicus Sentinel 2 MSI: fine scale/coastal


Intelligent image acquisition

Digital Micromirror Device

- Array of millions of micromirrors
- Each mirror has binary reflection response
- Dither patterns (off/on patterns) can be adjusted at 40 kHz
- Allows highly flexible front end optical filtering
CubeSat DMD Imager Design

- Place a **Digital Micromirror Device (DMD)** in optical path
- Image a linear spatial scene onto the DMD in the vertical dimension $V$, hyperspectral bands in horizontal dimension $N$ (i.e., pushbroom type imager)
- Replace array detector with highly sensitive single detector (e.g., PMT or APD)
- **Decrease data loading** to $M \ll (V \times N)$
- Use **adaptive filter codebooks** (i.e., DMD dither patterns) to maintain SNR under different environment conditions
- **Image reconstructed at ground station** using complimentary codebook
- Ocean color, thermal, bioluminescence...
CubeSat DMD Imager Design

Key benefits with respect to current state-of-the-art (CCD/CMOS-based)

- Simpler, low SWaP-C optical design
- High spectral and spatial resolution possible
- A single PMT (or APD) detector with higher sensitivity, dynamic range (up to 2 orders higher), and SNR
- Interpixel non-uniformity errors, striping are avoided
- Front-end filtering to reduce redundant data loading with same SNR
- DMD dither pattern can be adapted in real time to optimize spatial-spectral resolution for a given scene
- DMD filtering can be used to mitigate blooming/saturation effects for bright land and cloud features adjacent to dark water
- Far less data volume transmitted with near-lossless compression
CubeSat DMD Imager – specs for Navy project

- Minimum SNR of 300 across all bands
- 350 to 900 nm spectral range, up to 1600 bands
- 20 m GSD over 50 km swath at 450 km altitude
- Equatorial orbit planned with ~90 min revisit
- Compressive sensing to optimize information content while achieving SNR
Mission/Payload Sensor

FY19: 854 x 480 pixel DMD
6.2 x 5.8 x 3.6 cm³

FY20:
2560 x 1600 pixel DMD
SPAWAR Systems Center Pacific Launch Program

- Phase A simulation and testing
  - Thermal vacuum, vibration, radiation, etc
  - Power budgets
- Material and hardware durability/reliability assessment
- Integration design with 6U bus
- Simulate and test data downlink
  - ~1 Mbps over ~5 min/orbit
  - Developing optical comm downlink with 120 Mbps capability
  - Also developing optical comms in space for real-time downlink from anywhere in orbit
High Altitude Platforms (HAPs): winged

Zephyr (Airbus)
Pioneering the Stratosphere
Model **AlphaLink X**

- **Number of Aircraft:** 10
- **Total Wingspan:** 215 m
- **Payload Capacity:** 450 kg
- **Operational Latitude:** 40° N/S
- **Continuous Operation:** 365 Days

AlphaLink X is powered by solar energy and allows flexible mission rescheduling and maintenance work during flight.

Operating at altitudes of 20 to 30 km

**High-aspect-ratio wing with increased payload capacity**

[Image of High-aspect-ratio wing with increased payload capacity]
High Altitude Platforms: balloons

Raven (Aerostar)

High Altitude Long Endurance Demonstrator (HALE-D) (Lockheed Martin)

LTE Airnode (Airbus)
European missions for Aquatic Earth Observation: a new observation class on the horizon?
Summary

• Currently developing hyperspectral DMD imager
  • 854 x 480 DMD increased to 2560 x 1600 in FY20
  • Phase B CubeSat deployment in equatorial orbit, FY21
• Flight operations testing at SSC-Pacific
• Navy support for bioluminescence and thermal imagers pending
• Phase A testing on HALE platforms with SSC-Pacific
• Working on contributing a DMD imager for EU Open Cosmos CubeSat for ESA
• Postdoc opportunities

Thank You  mtwardowski@fau.edu
Compressive Sensing Algorithms

- **Compressive Line Sensing (CLS):** highly resource efficient technique
  - Inspired by active CLS imager prototype previously developed for Navy and Air Force
  - Senses each spatial-spectral “sheet” independently, jointly reconstructing a set of “sheets” for data cube
  - Imaging = *encoding/decoding*
  - DMD codebook applied adaptively, “on-the-fly”

**Underwater imaging through bubble screen**
Science Products – Ocean Properties

- Fundamental optical properties of water
  - absorption
  - backscattering

- Biogeochemical properties
  - Suspended Particulate Matter (SPM)
  - Chromophoric DOM
  - Chlorophyll
  - Algal pigment composition
  - Particulate organic carbon (POC)
  - Primary productivity
  - Etc...

Imaging, visibility, Electro-Optical ID applications
Ecosystem monitoring, ocean health, hazard impacts
Development of bioluminescence and thermal imagers in review at Navy, FY19-20

• For persistent surveillance
• Same DMD front end optical filtering technique
  • For **bioluminescence**, full 2D scene imaged onto DMD at 490 nm
  • For **thermal**, full 2D scene imaged onto DMD at MWIR
• Sparse background monitoring switches to intensive monitoring protocol with object detection
• Testing proposed from geostationary orbit on CubeSats (~2 m GSD) and HAPS drones (~40 cm GSD)