Ocean Property Characterization Over EU Waters From a CubeSat With Novel Digital Micromirror Imaging System

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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 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
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
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*
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
- Passive water-leaving radiance ($L_w$) detected, aka Remote Sensing Reflectance
  - Libraries of algorithms exist to derive a wide range of ocean water quality parameters
Mission/Payload Sensor

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

**FY20:**
2560 x 1600 pixel DMD
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
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
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)
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 in review
  • Phase A testing on HAPS drones
• Interested in contributing a DMD imager for monitoring EU waters
• Postdoc opportunities

Thank You  mtwardowski@fau.edu