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LEVERAGING COMMERCIAL ASSETS, EDGE COMPUTING, AND NEAR REAL-TIME COMMUNICATIONS FOR AN ENHANCED NEW OBSERVING STRATEGIES (NOS) FLIGHT DEMONSTRATION

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ABSTRACT

Recent developments in New Space companies have led to a dramatic increase in capabilities in Earth Observation. These advances in edge computing, low latency communications, and many new on orbit assets represent a unique opportunity for Earth Observation. NASA's New Observation System (NOS) program aims to leverage these new capabilities to achieve global reach of science events such as volcanic eruption, wildfires, flooding, not by wide swath instruments but rather by intelligent, directed sensing, onboard analysis, and dissemination of knowledge rather than data using low latency communications links. We describe ongoing efforts to deploy NOS capabilities to the CogniSAT-6/HAMMER satellite launched in March 2024, with a currently projected flight demonstration of late summer or early fall 2024.

Index Terms— New Observation Systems, Sensorweb, New Space, Edge Computing, Intersatellite link

1. INTRODUCTION

NASA's Earth Science Technology Office is spearheading the New Observing Strategies (NOS) program, to enable dramatic new science observations at reduced cost by leveraging multiple air, space, ground, and marine sensors in coordination [1]. This program highlights the synergies between multiple emerging technologies including but not limited to: spacecraft and observation asset autonomy (can be space but also air, ground, marine, ...), instrument and spacecraft miniaturization, edge computing, and science modeling.

Prior sensorweb efforts have focused on leveraging the Earth Observing One (EO-1) Mission from 2004-2017 [2] and have included applications to track volcanic activity [3], flooding [4], wildfires [5], and other applications. Additionally, EO-1, even with extremely limited onboard processing, demonstrated onboard thermal detection [6] , flooding [7], and cryosphere (including cloud screening) [8] and other applications such as unsupervised learning [9]. EO-1 sensorwebs demonstrated the efficacy of sensorwebs for: (1) volcano monitoring [3] demonstrating an over 30% hit rate for capturing active thermal signatures over an order of magnitude increase of blind monitoring and (2) flooding [4] using global coverage moderate resolution MODIS to target narrow field of view but high spatial resolution EO-1, Worldview, Geo-Eye and others enabled a doubling of temporal coverage with high spatial resolution sensors.

More recent efforts to demonstrate a NOS sensorweb have included modeling to demonstrate tracking of flooding events [10]. This NOS testbed effort included demonstrations using Planet Dove, Skysat, and Capella SAR measurements. More recent large-scale demonstrations have leveraged the Planet Dove and Skysat constellations to track volcanic activity[11] (also using the ECOSTRESS instrument onboard ISS) and flooding worldwide [12].

Significant growth of extremely capable commercial Earth Observing satellites enable unique NOS capabilities.

- *Edge computing* Commercial companies are embracing space edge computing including specialized hardware (e.g. Intel Myriad and other neuromorphic computing and FPGA) and "conventional" processing for LEO spacecraft is becoming quite capable (e.g. 1-3 GHz CPUs are quite commonplace). Space edge computing enables onboard processing and analysis of acquired data and even tasking [13, 14] - reducing response latency.
- *Satellite Communications Link* Many new commercial constellations support modest data rate, near continuous access, low latency communications using com-

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mercial space communications constellations (whether in LEO, MEO, or GEO) offering the ability to link together assets with near constant (albeit low data rate) communications. This ”anytime” communications link reduces response latency.

- *Platform Proliferation* Leveraging reduces launch and platform costs, the existence of many medium and large scale commercial Earth Observation constellations means more revisits further reducing response times.

We advance sensorweb/NOS technologies by executing flight demonstrations building upon prior work and leverages these new developments.

Leveraging prior work in deploying onboard processing [15] and machine learning applications [16] to commercial edge processors (including Snapdragon, Intel Myriad, and NVIDIA), we seek to deploy such applications on the Intel Myriad X processor integrated on a Ubotica CogniSAT-XE2 processing board flying on the CogniSAT-6 (CS-6)spacecraft [17] that launched on Transporter 10 in March 2024.

Such demonstration will significantly advance prior flights such as IPEX Cubesat which demonstrated a range of onboard processing and analysis in space on both the ATMEL ARM processor and the Overa Gumstix payload processor [18] [19]. More recent work has included flight of advanced machine learning on ESA's OPS-SAT [20], flight of CNN's on Intel Myriad Neuromorphic hardware on ESA's Φ-Sat-1 [21], flight of generative AI for de-noising on ESA's OPS-SAT and even few shot machine learning training onboard D-Orbit's ION SCV004 satellite [22, 23].

2. NOS APPLICATIONS

We are currently developing deep learning and spectral analysis onboard processing algorithms for a range of science applications.

- Deep learning applications include: cloud screening, surface water extent (for flooding an hydrological applications), algal bloom/ocean color, and land use. Thermal analysis (volcano, wildfire) - with understood limitations without a higher wavelength (e.g. TIR)

- Spectral signature detection approaches includes spectral angle mapper, match filters, and spectral unmixing both using deep learning [16] and traditional means such as SMACC [24]

3. OPERATIONAL SCENARIO AND PROJECT STATUS

The NOS flight demonstration is in implementation for flight on the CogniSAT-6/HAMMER [17] spacecraft operated by Ubotica/Open Cosmos that launched in March 2024. CS-6 has several capabilities that make it well suited for the NOS flight. First, it hosts a visible range 0.4-0.9 micron hyperspectral instrument with a nominal 19km x 19km acquisition at approximately 5m per pixel. Second it hosts an Intel Myriad X for onboard computing. Third, it has an intersatellite link to enable for rapid dissemination of notifications and compact summary products.

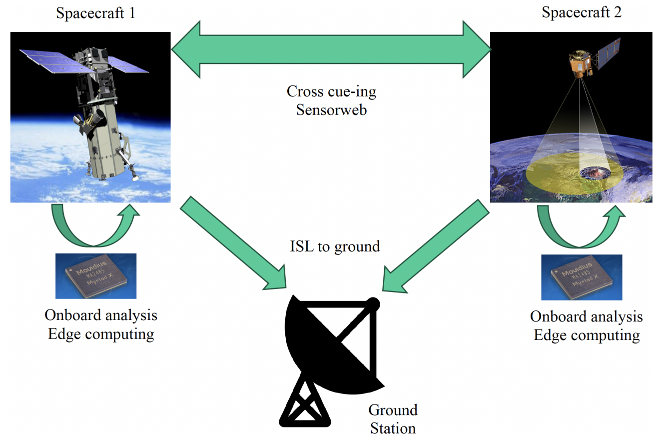

Fig. 1. Sensorweb/NOS enables cross-cues from spacecraft to spacecraft. Edge computing used for onboard observation analysis. Inter-satellite link enables low latency communications to ground stations.

The specific NOS demonstration scenario will be as follows (see Figure 1).

- CogniSAT-6 overflight and image acquisition

- Onboard analysis of said image using Intel Myriad computation

- Generation of alert if said analysis warrants. Rapid downlink of said alert via inter-satellite communications link to ground.

- Ground receipt of said alert and used to trigger tasking of of followup observations. Current plans are to task Planet Skysat [25], task ECOSTRESS [26] if thermal detection. We are also investigating potential tasking of the EMIT instrument [27].

- Acquisition of followup imagery (e.g. Planet Skysat sub 1m per pixel visible imagery)

- Downlink and receipt of both CogniSAT-6 and Planet Skysat imagery

- Retrieval of relevant Planet Dove imagery

We are also investigating the use of other satellites as either the initiator or as the responding satellite.

4. PROJECT STATUS AND CONCLUSIONS

As this article goes to press in early May 2024, a first set of onboard image analysis applications have been developed and are in testing for flight validation.

The current focus is on a core set of applications as indicated below.

- Machine learned convolutional neural networks (CNN) leveraging the Intel Myriad hardware onboard CS-6. For these we are using the U-Net [28] model architectures. These learned models target cloud detection, surface water extent (flooding), and land surface type (e.g. city, forest, water, desert,...) classification.
- Spectral analysis includes common methods like spectral angle mapper (SAM), match filters (MF), and the Reed-Xiaoli (RX) anomaly detector; as well as spectral unmixing using deep learning [29].

The development and testing process begins with training of deep learning models on MacOS laptops. These models are then deployed to Myriad X Neural Compute Stick(s) for further testing. These models are then tested on a flatsat testbed at Ubotica before final upload and use onboard CogniSAT-6.

Because CogniSAT-6 data is limited due to its recent (March 2024) launch we leverage Planet Dove Planetscope data and data from the Open Cosmos Menut satellite. From the Dove datasets we use the red, green, blue and near infrared spectral bands to approximate the CogniSAT-6 Hyperscape sensor data data. As Dove is global daily coverage we have access to a large amount of data and are currently using a dataset of hundreds of scenes. From the MENUT dataset we are using the red, green, blue, and near infra-red spectral bands and currently have access to 180 scenes. These spectral bands are then mapped to the CogniSAT-6 Hyperspectral visible range instrument as indicated in Table 1.

For machine learning training runs we restrict to datasets of 50-100 relevant images to keep training times manageable. We are working also to get CogniSAT-6 test data.

For the above leading applications, as this article goes to press in May 2024, we are currently in laptop and Myriad X compute stick testing. We are targeting transition to flatsat testing in the June-July 2024 timeframe and targeting flight onboard CogniSAT-6 in late summer - early fall 2024 timeframe.

This paper has described the planned in space test of onboard data analysis using artificial intelligence/machine learning and other methods leveraging edge computing onboard the CogniSAT-6 spacecraft launched in March 2024. Onboard analysis algorithms for multiple applications are in development and have moved from laptop/workstation testing to Myriad compute stick testing as of May 2024. These applications are expected to proceed to flatsat testing in a few months with anticipated in flight testing late summer or early fall 2024.

Spectral Band	Dove-C	Dove-R	Menut	CS-6
Blue	455−515	431−452	457.5−522.5	485
Green	500−590	547−585	542.5−577.5	560
Red	590−670	650−682	650.0−680.0	664
NIR	780−860	846−888	784.5−899.5	830

Table 1. Red, green, blue and near-infrared bands used by onboard analysis - machine learned classifiers and spectral classifiers. Band ranges or center points indicated in nm.

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