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ESA Earth Observation Directorate NewSpace initiatives

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ABSTRACT

The paper presents the first scientific and technology initiative of the Earth Observation directorate in the NewSpace field under the generic name of Φ-Sats. Φ-Sat-1 is the result of an enhancement of the FSSCAT[1] mission using Artificial Intelligence (AI) and improved imaging capabilities of the Hyperspectral-1 VNIR imager. Φ-Sat-1 is an innovative concept using a Hyperspectral/TIR optical payload (HyperScout®-2) for land and water applications as well as specific applications on the field of terrain classification and change detection. The instrument will also embark a demonstrator technology package consisting of an AI chip, to perform innovative cloud detection and masking on hypercube data. Φ-Sat-1 will be launched in Q3 2019 with the Vega SSMS Proof-of-Concept (POC) maiden flight.

INTRODUCTION

In recent years, the space sector has seen a paradigm shift called NewSpace leveraging new and augmented commercial and scientific opportunities. A plethora of new actors have entered the space engineering world creating business opportunities, as well as scientific opportunities. The European Space Agency (ESA) has always followed the growth of this NewSpace world, particularly in terms of technology development and experimentation. In fact, ESA has developed many In-Orbit Demonstration (IOD) missions based on quick and low cost NewSpace CubeSat. This strategy led to a portfolio of technologies available for the users and opportunities to increase European based capabilities in this field.

The technology maturity and capabilities reached in Europe nowadays allow for the development of comprehensive scientific missions (supporting scientific communities), as well as the launch of initiatives to invest and support European commercial industries. Φ-Sat-1 represents the first of these initiatives supported by the ESA Earth Observation Directorate obviously focused on the Earth observation domain. This initiative addresses both scientific and technological objectives. Φ-Sat-1 is the results of the enhancement with artificial intelligence (AI) technology of an advanced hyperspectral and thermal infrared imager.

INITIATIVE

Φ-Sat-1 has a twofold objective: to demonstrate capabilities for scientific applications and to validate in-orbit specific innovative technology. In particular, for the former, it is mainly devoted to co-registered acquisition of the VNIR and TIR channels for terrain classification and change detection. As to the technology demonstration, the mission will embark an AI-based inference engine for cloud detection.

Overall the objectives are reached by means of a hyperspectral camera with VNIR and a TIR channel and a VPU (Video Processing Unit) for AI.

The mission has two main original aspects:

1. It will be the first CubeSat mission to acquire full co-registered images in the visible near-infrared and thermal infrared regions;
2. It will be the first flight demonstration of AI inference engine for cloud detection demonstrating the capabilities of Myriad chip;

Φ-Sat-1 will be launched in Q3 2019, as enhancement of the FSSCat mission, during the VEGA SSMS Proof of Concept flight. Table 1 summarizes the orbital parameters of the injection orbit. The satellite does not have orbit control capabilities so its orbit will drift.

Table 1: Orbit parameters

Parameter	Value
Altitude	540 km
Eccentricity	~0
Inclination	SSO
LTAN	10:30 a.m.

APPLICATIONS

HyperScout®-2, the instrument utilized for Φ-Sat-1, will be used to acquire hyperspectral images for land and water application using both VNIR and TIR channels.

Images will be acquired for both land surfaces and hydrosphere to demonstrate the potential applications which can be addressed using CubeSats.

Figure 1 shows the different applications that will be demonstrated using the VNIR and the TIR channels of the hyperspectral instrument.

Thanks to the co-registered acquisition of the VNIR and TIR images, which give the possibility to measure simultaneously and over the same location both the solar albedo and the thermal emission, HyperScout®-2 will provide additional important information to facilitate the understanding of the phenomena that can be studied with solar albedo and thermal emission data. Among these include: water quality of in-land and coastal waters, investigating detection capability of variables such as chlorophyll, organic matter and suspended matter .

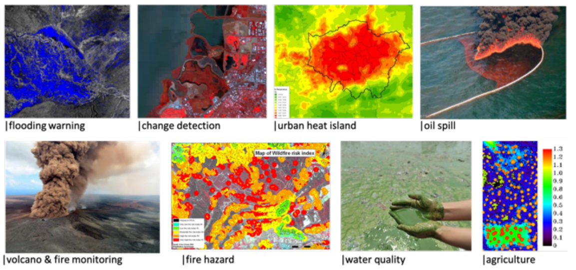


Figure 1: Land and water applications example

AI CLOUD DETECTION EXPERIMENT

The AI cloud detection experiment is aimed at validating the performance of an on-board inference engine based on a machine learning algorithm for cloud detection. This is the first time such an experiment will be conducted in space. The inference engine will run on a VPU embedded[3] in the hyperspectral instrument and it will aim to improve the content of the downloaded data. In fact, one of the key issues for hyperspectral instrument embarked on small satellite/cubesat mission is lowering cost, both economic and in terms of reducing on-board resources (power, mass and maximising contact time), vs information for the downloaded data. Whilst, a hyperspectral mission produces an incredible amount of information from any observed scene, in many cases for land, hydro and cryo-sphere observations, the data are not exploitable due to the presence of clouds. For instance, in the case of Sentinel-2, more than 30% of the images are cloudy.

This experiment will demonstrate that an inference engine based on machine learning can significantly reduce the number of cloudy images with negligible loss (<1%) of significant data.

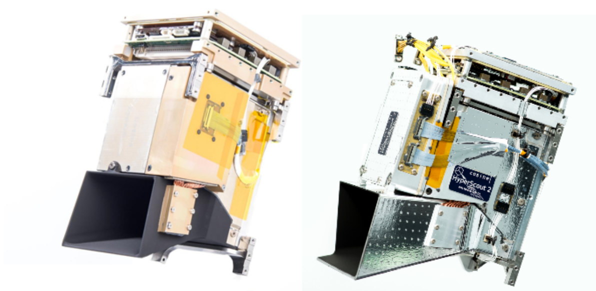
The experiment will be run using the images acquired by HyperScout®-2 and for this IOD phase both the inferenced images and the original images will be downloaded to verify the effectiveness of the algorithm.

HYPERSCOUT®-2

The HyperScout®-2 is an enhanced version of the Hyperscout-1[2] sensor flying on the Gom-X4 mission. The main advancements of HyperScout®-2 with respect to the version now flying is the addition of a TIR channel with 4 additional bands and additional AI elaboration capability through an additional VPU chip. Consequently HyperScout®-2 is equipped with two spectral channels, each with 2D sensors operating in pushbroom mode, a VNIR (400 - 1000 nm) and a TIR (8 - 14 µm). The internal computational capability includes a CPU, a GPU and a VPU giving HyperScout®-2 an unprecedent computational power and allowing real time generation of Level-1 and Level-2A data as well as AI inference capabilities. The VNIR camera is being funded by the new ESA Investing in Industrial Innovation (Incubed) co-funded programme.

The overall volume, mass and power consumption increment with respect to Hyperscout-1 are negligible.

Figure 2 shows the two FM side by side and allow to appreciate the similarity.



1 2

Figure 2: Hyperscout 1 and 2 FMs

Hyperscout VNIR channel is based on a Fabry-Perot filter laid directly on the sensor while the TIR channel is based on a thermally-stabilized microbolometer with a band pass filtering approach. The telescope is a highly compact reflective system with F4 (VNIR) and F2.5 (TIR) thanks to adoption of free-form optics.

Table 2 summarizes the main characteristics of HyperScout first and second generations.

Table 2: Hyperscout-1 & -2 characteristics

Parameter	Hyperscout-1	HyperScout®-2
Orbit	500 km	540 km
FoV (ACT c ALT)	23° x 16°	CH1: 31° x 16° CH2: 31° x 16°
GSD	~70 m	CH1: 75 m CH2: 390 m
Swath	~ 200 km x 140 km	CH1: ~ 310 km x 150 km CH2: ~ 310 km x 150 km
Active pixels	3000 x 1850 px	CH1: 4000 x 1850 px CH2: 1024 x 768 px
Spectral range	400 nm – 1000 nm	CH1: 400 nm – 1000 nm CH2: 8 µm – 14 µm
Spectral bands	Contiguous 45 bands	CH1: 45 CH2: 4
Spectral resolution	16 nm	CH1: 16 nm CH2: B1: 1.1 µm B2: 1.1 µm B3: 1.1 µm B4: 6 µm
SNR (NeDT@300K)	50 – 100	CH1: 50 – 100 CH2: (0.5 – 3 K) * NeDT improvement with temporal and spatial averaging will be experimented

AI NETWORK

As mentioned above Hyperscout has been embarked with a VPU to maximise the AI inference capability in real-time. In particular a Movidius board mounted on a Myriad II chip (VPU) has been added to HyperScout®-2's electronic stack. The Movidius board is connected to Hyperscout through a fully protected power line as well as USB-2 connection for data exchange. See Figure 3.

Figure 3 shows the data pipeline performed on-board Hyperscout.

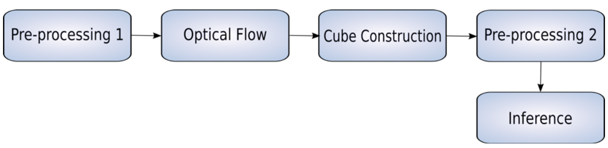


Figure 3: Hyperscout data processing pipeline

Before the cloud inference occurs, a platform independent algorithm for reconstructing the spectral data cube is performed. The current approach is to apply an optical flow methodology. To estimate the dense flow fields, the neighborhood of each pixel is approximated with a polynomial, which allows for efficient translation (flow) estimations.

Figure 4 shows an exploded view of the Movidius board on the HyperScout®-2 electronic stack

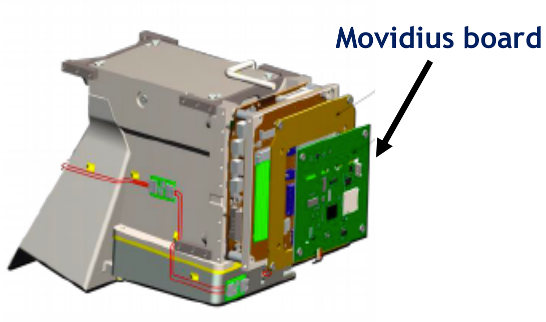


Figure 4: Movidius board on Hyperscout electronic stack

END USER PRODUCTS

The end goal of the mission is to provide to the scientific community with user product up to level 4. In particular the mission will generate:

Level 0

Payload data (HyperScout-2 VNIR and TIR channels) as Source Packets with added product headers, chronologically sorted by Source Packet type: Observation Data and Housekeeping Telemetry.

Level 1A

Raw data with associated latitude/longitude, solar angles and satellite viewing angles per pixel.

Level 1B

HyperScout-2 data radiometrically corrected using known homogeneous targets (ocean, rain forest, deep sky…).

Level 1C

L1B reshaped into spectral band images

Level 2A

Level 1C mapped and projected on a standard cartographic projection (e.g. UTM WGS84).

CONCLUSIONS

This paper presented the first scientific and technology initiative in the field of NewSpace developed by the Earth Observation directorate of the European Space Agency. Φ-Sat-1 will have many "firsts", technologically and scientifically, despite the reduced budget and tight schedule. Φ-Sat-1 will be launched as enhancement of the FSSCat mission, in Q3 2019 with the Vega SSMS POC maiden flight.

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