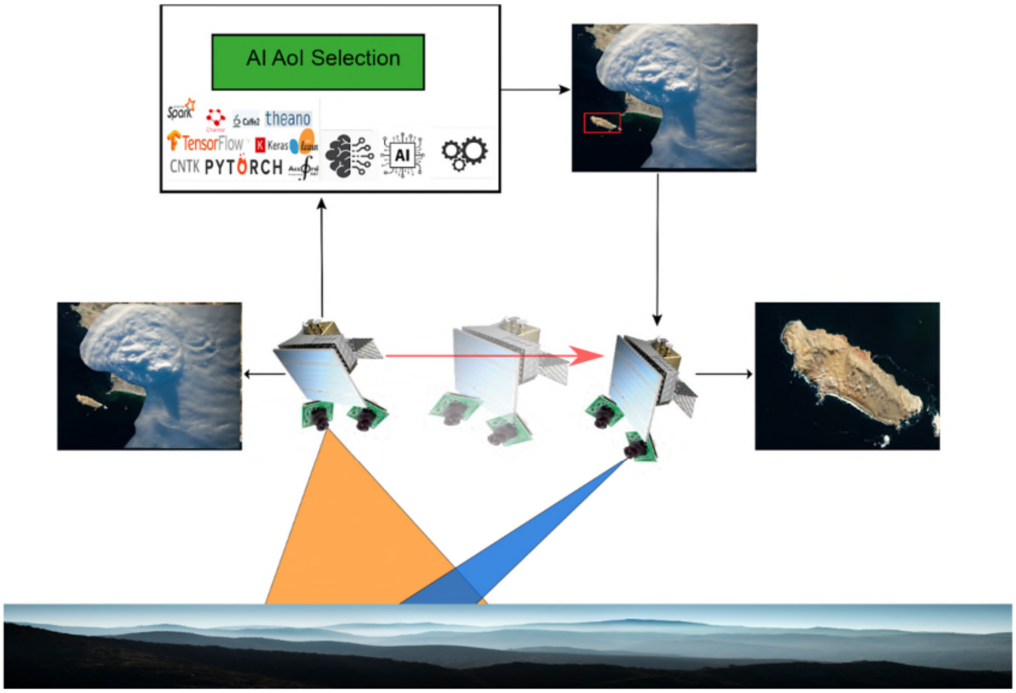

IDEA: I-2022-00382 – Dual camera satellite with on-board AI-based decision-making capabilities

Executive Summary Report

study

EISI – Studies Proposals

Campaign - Cognitive Cloud Computing in Space

Affiliation(s): OHB-Hellas (Prime), FORTH (Subcontractor)

Publishing Date: 1.11.2022

Contract Number: 4000138071

Implemented as ESA Initial Support for Innovation

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Activity Summary:

The main objective of this study is the evaluation of the merits of a dual camera setup for the acquisition of both high spatial resolution images and high-resolution images of identified events of interest, on-board, through AI methods. The feasibility of the approach on a mission-level concept of a single-satellite, dual camera setup as well as a two-satellite (leading-trailing), single camera setup was investigated. The AI approach was demonstrated on commercially available representative high-performance on-board computers (Xilinx Kria SoM / Google Edge TPU SoM) through a state-of-the-art fire detection use case.

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Title
ESR: Executive Summary Report

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Implemented as ESA Initial Support for Innovation

Change Log

1	First Release	all
Revision	Reason for Change	affected chapters/pages

	author	checked	released
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Signature	Simon Vellas (Dec 8, 2022 13:48 GMT+2)		
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1 Introduction

This document constitutes the Executive Summary Report of the Project, summarizing the findings of the Contract in a concise way. This Summary is not meant to provide an extensive analysis of the work performed during the activity but rather give a high-level overview of it.

2 Applicable Documents

AD No. / Title	Doc. No.	Issue
AD1 Idea I-2022-00382: 2nd Round: Dual-camera satellite with on-board AI-Based decision-making capabilities		1

3 Related Documents

RD No. / Title	Doc. No.	Issue

4 Main Part

4.1 Existing – EO solutions

Geosynchronous satellites, like Meteosat Second Generation, are able to constantly observe (every 15 minutes) parts of the globe, Europe in particular at a coarse resolution (1km). Low-Earth Orbit (LEO) satellites, on the other hand, operate at 400-600km orbits offer the ability to image at much higher spatial resolution. Within the LEO orbit, we can identify two cases of missions, institutional missions like ESA Sentinel 2, which focus on global coverage at moderate resolution (10m), and commercial missions like Worldview which operate under a fixed schedule but acquire images at very high resolution (<0.5m).

The diversity in terms of mission types can be attributed to the fact that imaging characteristics are constrained by physical laws like the diffraction limit, as well as technological ones like detector element size. As a result, no single existing platform can satisfy the requirements for high spatial and temporal resolution. Satisfying these requirements is however necessary for applications like extreme event monitoring where both low latency and high spatial resolution can have a significant impact on life and property. Furthermore, the potential of EO in these applications is also heavily dependent on the ability to analyze the massive amounts of observations acquired by such platforms.

While EO mission designs focus on ever reducing the size and complexity of satellite platforms, the proliferation of data analysis algorithms is effectively addressing the observation deluge. In the current paradigm, data analysis algorithms, and more specifically deep machine learning algorithms are introduced on the ground using high-performance processing platforms like multi-GPU servers with access to very large amounts of observations. Despite their unquestionable usefulness, these concepts still rely on traditional mission designs where EO satellites take observations, process them and send them to the ground. In this proposed idea, we argue that the power of AI can also act as an enabler for new mission concepts.

4.2 Proposed framework

In the case of earth observation missions, the ideal remote sensing solution would be a large swath camera with a large field of view, high spatial resolution, and high revisit and response time, all at the same time. However, the implemented solution is in reality a compromise between these factors. The main objective of the project is to demonstrate how novel classes of missions can be realized by introducing deep learning observation analysis approaches onboard the satellite. As a representative case study, we consider the implementation of a novel satellite platform design that considers platforms equipped with two cameras with different imaging characteristics acquiring imagery.

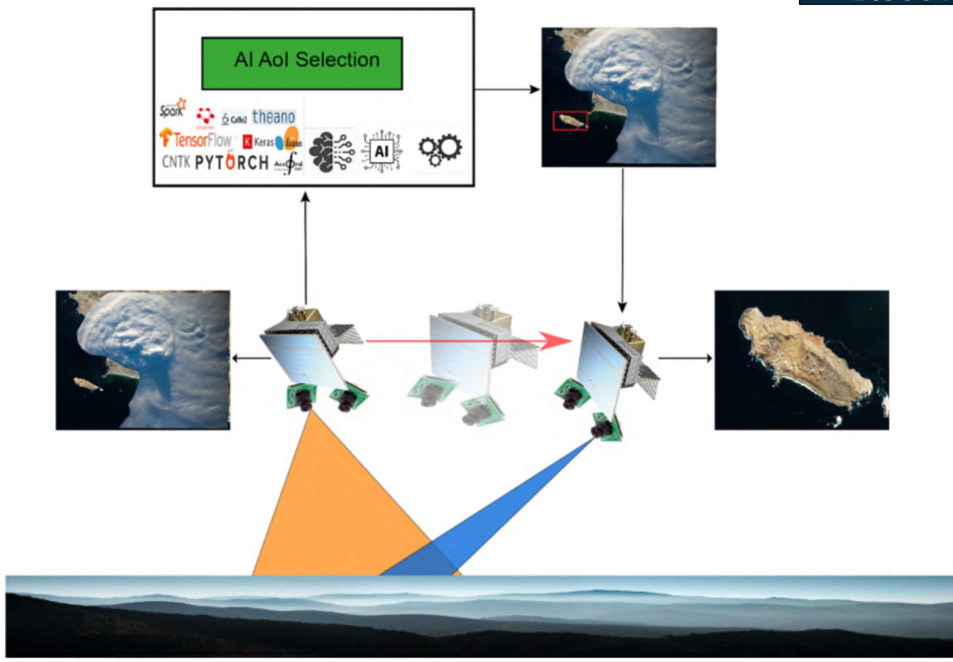

Figure 1: Overview of the DUAL-CAM concept

In our proposition, the objective is to have a wide-swath optical camera for the maximization of the coverage, combined with a high-resolution, narrow-swath camera to achieve the highest required spatial resolution and get the best possible image of an Area-of-Interest (AoI).

Selecting different camera/optics configurations of the two cameras will lead to different swaths, i.e., revisit periods, and spatial resolution. In the proposed mission concept, the first camera could be placed as forward-looking and is characterized by a large swath but relatively low spatial resolution and is responsible for capturing images with a large field of view.

The second camera is nadir/backward-looking and can be pointed to acquire images of specific Areas-of-Interest within the field of view of the first camera but at a significantly larger spatial resolution. In this concept, the decision on which AoI the second camera will focus is performed by an intelligent AI-enabled control module that analyses the observations from the first camera in order to provide the necessary signals to the control of the second camera.

In terms of specific imaging scenarios, we can identify different scenarios, including:

- A pair of low and high spatial resolution RGB cameras.
- An RGB camera for still image capturing and an RGB camera for video capture.
- An RGB - MS camera pair, where the second camera is of similar spatial resolution (but limited FoV) and can obtain MS observations.

In the proposed concept, the decision on which AoI the second camera should select is performed by an intelligent AI-enabled control module that analyses the observations from the first camera in order to provide the necessary signals to the control of the second camera. The AI-enable AoI selection takes the coarse observations from the first camera and executes a process that will assign specific values to the different regions. The value is derived from the expected reward associated with taking a specific action, in this case selecting to image at HR one or more AoIs. The AI-enabled imaging control system will be realized through onboard Deep Reinforcement Learning.

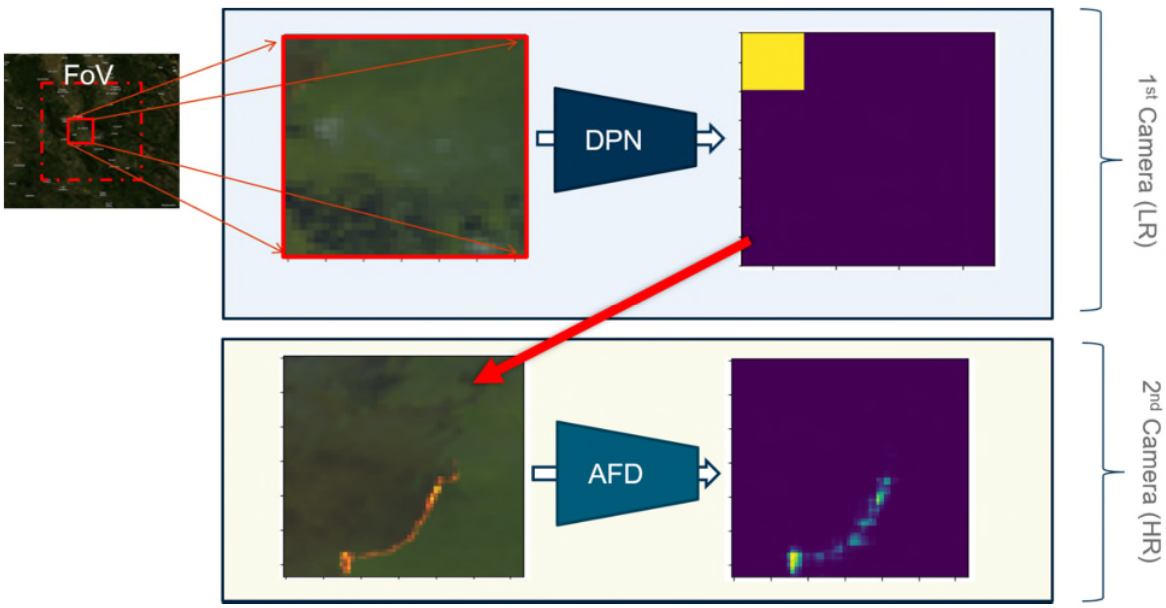

Figure 2: Illustration of DUAL-CAM operations for the two camera models

4.3 Application domains

The dual camera concept as described above provides great benefits in different aspects of EO and application scenarios. By having an AI on board that can dynamically assess the current conditions and selects which action to take, the cost of data is reduced since the platform will only downstream data that the algorithm has denoted as of interest. Subsequently, the platform's operation is flexible in nature as it can calculate and execute orbital adjustments by itself, given the current environmental conditions (e.g. cloud coverage percentage, the dynamic event of interest). As an added benefit from its autonomous capabilities to self-orient, the operational cost can be further decreased since the proposed platform does not require the same manpower needs for pre-planning activities in traditional operational approaches. The platform can also achieve reduced latency in capturing data, made possible due to its autonomous operations and on-board data processing, thus paving the way for new applications focusing on emergency response, disaster monitoring, and time-critical domain, especially for capturing high-resolution images of unplanned/sudden events. The satellite EO capturing abilities are further enhanced due to the modularity in its operation and the capability of changing and adapting the AI model to a variety of use cases. An example of the application of the proposed concept for land cover change detection is shown in the follow table which indicate initial and new land cover (LC) classes and the domain where such changes might be interesting.

Table 1 - Land cover change detection use case example

Initial LC class	New LC class	Domain
Sparsely vegetated areas	Construction sites	Urbanization
Forest	Burned area	Forest fires
Non-irrigated land	Permanently irrigated land	Agriculture
Green urban areas	Urban fabric	Sustainable Development
Semi-natural land	Wetland	Flooding
Natural and semi-natural land	Cropland	Biodiversity
Mixed forest	Agro-forest	Climate change

In brief, the AI-enabled core benefits derived from the proposal's objectives are as follows:

- Multi-Swath dual camera architecture system capable of Large Swath and HR imaging.
- Cost-efficient system in terms of speed of data acquisition and quality of data.
- Adaptively detect and capture data of dynamic Areas-of-Interest (e.g. specific events of interest, a significant change of land cover, etc.).
- Intelligent approach, further expanding the capabilities of Earth Observation applications.
- Lower bandwidth consumption, and efficient usage of bandwidth (ensure transmission of HR data).
- Further develop autonomous capabilities of space vehicles (e.g. autonomous satellites, intelligent constellations).

4.4 Mission analysis

A feasibility study was performed to identify the satellite platform in which the dual camera system would be hosted. Initially, a single satellite equipped with a tilted, forward looking low-resolution camera and a high-resolution camera as well was considered. The satellite would adjust its attitude after the AoI identification and capture the high-resolution image. This scenario is feasible but a critical constraint is introduced between the capturing of the LR and the HR image because of the satellite tilting and settling time, thus leading to the assessment of other solutions.

In a second iteration, a two - satellite system that can be utilized to implement the dual camera concept was studied. One satellite, the “scout” would be equipped with the low – resolution camera and an AI accelerator to detect the AoI, while the second one, the “fine - pointing”, would be equipped with the high – resolution camera and an AI accelerator to perform other required processes. Thus, the scout would be responsible for capturing the wide field of view image, locating the AoI and transmitting the required data to the fine - pointing satellite. The latter would be receiving the data, performing the necessary attitude corrections and capturing high-resolution images. The satellites would be on the same orbit with a relative distance between them. In this scenario, the total time available between the LR and the HR image capturing is defined by the said relative distance and must include the satellite tilting and settling time, as well as the time required for the AI processing to take place. This scenario is feasible and could be implemented in a space mission for an AI on-board application execution.

4.5 Case study on active fire detection

By utilizing a multi-swath dual camera architecture, it is possible to capture HR data of interest “on the first try” thus dramatically reducing revisit time. The cost of acquiring HR data further decreases since this technology can enable the collection of more relevant data in a shorter amount of time and at the same time provide a form of “quality assurance”. Moreover, by dynamically selecting Areas-of-Interest based on AI-derived decisions, it is possible to have a framework allowing reconfigurable Earth Observation missions, capturing data on the fly from dynamic events that were not in the original scope of the given mission. The proposed approach can be applied to monitoring numerous parameters and phenomena of interest including land cover changes, extreme weather events, and natural disasters

To demonstrate the merits of the proposed idea, we explore the case of Active Fire Detection (AFD). Given an image of a scene acquired by a satellite, the objective in AFD is to classify each pixel (i.e. spatial location) as part of an active fire front or not. We consider publicly available data from Landsat 8 and associated annotated to demonstrate the potential of the proposed work

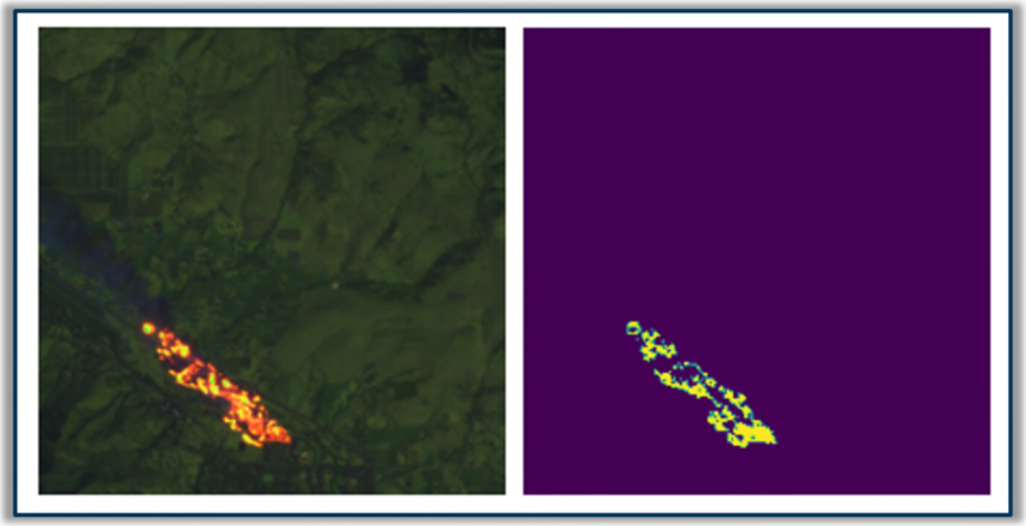

Figure 3: Example of satellite image (left) and active fire mask (right) used in our study

It is interesting to note that the Copernicus Active Fire Detection service, part of the European Forest Fire Information System (EFFIS) utilized NASA Fire Information for Resource Management System (FIRMS) for providing rapid response typically a few hours after acquisition.

An indicative example is shown in the following figure, where: (i) The top left panel shows the image acquired by the 1st (LR) camera, (ii) the top middle panel shows the ideal HR fire map. This image is not available to the platform since it assumes an AoI as large as the 1st camera's FoV. This map is thus shown for reference, (iii) the top right panel shows the selected AoI. The image is 4x4 corresponding to the 16 potential AoI by the 2nd camera, (iv) the bottom left panel shows the HR AoI acquired by the 2nd camera, given the output of the DPN network, (v) the bottom middle panel presents the active fire front segmentation by the AFD network. This network assumes the HR AoI as input and can be optionally executed on the platform, and (vi) the bottom left panel presents the manually annotated active fire front for the HR AoI patch.

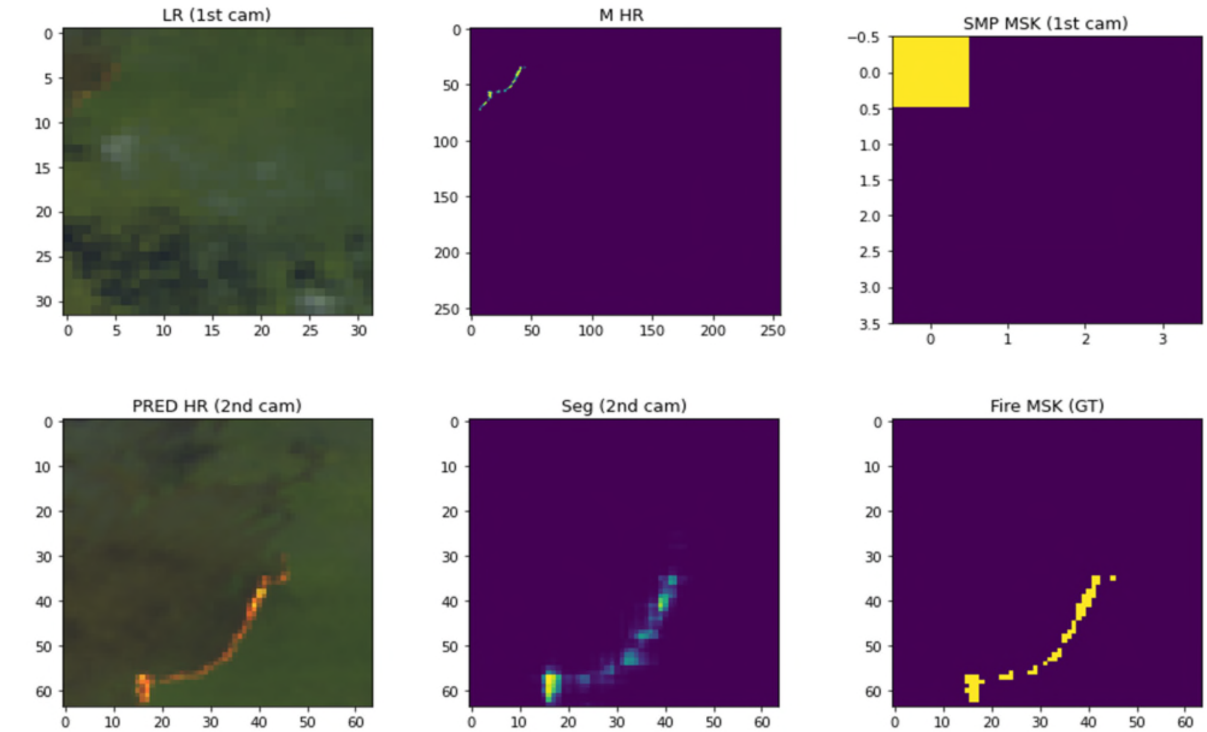

Figure 4: Active fire detection implementation

4.6 Demonstration of the use case

A demo was conducted in the premises of OHB Hellas in order to simulate the two satellites implementing the fire detection application.

The first device is simulating the scout satellite while the second device, the fine-pointing satellite. Initially, the 1st script executing on the first device reads a low resolution image stored in the device and identifies different regions in the image as <fire> or <not fire>. After that, the location of the detected fire is transmitted to the second device. The second device receives this information and runs a second AI algorithm on a High-Resolution image of the fire to identify the exact outline of the active fire.

Figure 5 - Demonstration setup

4.7 Discussion

By introducing AI technologies for delivering new types of products and capabilities, a new mission concept is proposed. This concept is only made feasible if onboard edge AI is considered given the real-time performance constraints. We employ the onboard AI software to make intelligent decisions addressing the need for more agile platforms. We focus on the case of EO, however, the concept is also applicable to other space exploration missions like observations of moons and asteroids. The key idea can also be appreciated in the context of autonomous robotic platforms for tasks like planning. Furthermore, we consider a single platform, although the proposed approach can be extended to multi-satellite missions.

The proposed idea enables the realization of novel EO applications on reconfigurable satellites targeting national agencies and commercial customers through a flexible Satellite-as-a-Service business model. The proposed AI-enabled technology is an initial stepping stone in developing more complex and advanced missions, with greater scope and capabilities of increased intelligence. Examples of such capabilities include the deployment of a constellation where the array of satellites could cooperate in capturing data (e.g. failure from one satellite to capture on the first try, deploy the closest satellite to capture tagged AoI if possible) as well as processing, distributing or even storing data.

221207_ESR_Executive_Summary_Report_DualCamera_OHB-HELLAS

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