AUTONOMOUS OPERATIONAL SCHEDULING ON COGNISAT-6 BASED ON ONBOARD ARTIFICIAL INTELLIGENCE

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ABSTRACT

To enable the Earth Observation space systems required to serve the needs of life on Earth in the near future, these systems need to operate more efficiently and autonomously. Artificial Intelligence can be deployed on the edge on spacecraft to provide this required increased autonomy. CogniSAT-6, an upcoming CubeSat Earth Observation mission by Ubotica and Open Cosmos, will leverage this technology to interpret captured images and use this extracted information to autonomously schedule operations without any input from ground. This capability greatly increases the efficiency of Earth Observation systems and enables tip-and-cue scenarios.

Key words: Autonomy; Artificial Intelligence; Scheduling; Earth Observation.

1. INTRODUCTION

In Q1 2024, Ubotica and Open Cosmos will launch a commercial mission called CogniSAT-6. CogniSAT-6 is an Artificial Intelligence (AI) centric 6U CubeSat that will carry the CogniSAT-XE2 processing board, a hyperspectral imager, and an IoT communication system. This unique combination of subsystems enables operational capabilities that: 1) increase the amount of valuable information an Earth Observation (EO) system can collect by up to an order of magnitude, 2) increase the speed of information delivery to end users by orders of magnitude, 3) open up new use cases and systems not previously feasible. This work details one out of a number of novel operational capabilities implemented in the CogniSAT-6 system: the ability to autonomously schedule operations based on the output of onboard data interpretation by AI. In addition, this work explains the benefits of AI-centric EO space systems and gives examples of the new use cases and systems that this technology enables.

2. RELATED WORK

While spacecraft operations are highly automated, operations for EO systems are rarely both dynamic and automated. Dynamic operations, defined here as content-responsive operations that allow a system to consider the content of its measurements in the planning and execution of operations, currently often require either a human-in-the-loop or a ground-based interpretation of data. Notable exceptions exist, but have been rare.

An example of a mission with integrated dynamic and automated operations is the EO-1 mission, which demonstrated onboard decision making algorithms that modified the operational schedule of the spacecraft to maximize scientific output of the system [1; 2]. This mission did not apply neural networks to payload data onboard.

An autonomous planner used to autonomously reschedule operations based on the output of a classification neural network has been developed for OPS-SAT and tested on a ground setup [3]. However, OPS-SAT only has low resolution imaging capabilities, limiting its ability to detect features for autonomous decision making. In addition, the hardware constraints of OPS-SAT are arguably limiting the compatible neural network architectures to smaller and less capable networks.

The Intelligent Payload Experiment (IPEX) was a 1U CubeSat launched in December 2013 that demonstrated autonomous operations [4]. The spacecraft had a sophisticated onboard planner called CASPER. This system demonstrated the use of machine learning for onboard data processing, such as imagery, and the use of detected features within this data to schedule follow-on acquisitions. The used onboard machine learning techniques did not include neural networks, and the system had low resolution imaging capabilities.

NASA has developed MEXEC, an *"onboard planning and execution software that uses task networks to generate and execute conflict-free schedules to achieve goals."* [5]. MEXEC was demonstrated on the ASTERIA CubeSat in 2020 [6]. This experiment showed that it is feasible to integrate highly capable planning software on a constrained environment such as a CubeSat, but did not utilise information extracted on board from payload data in its operational planning.

To the best knowledge of the authors of this paper, the use of neural networks in the context of onboard operational scheduling for EO spacecraft has not been demonstrated, nor has the use of onboard decision making algorithms been demonstrated in a commercial mission. The use of neural networks enables the robust interpretation of complex data like hyperspectral datacubes, whereas the usage of a low-cost and standardized CubeSat platform allows for both rapid development of a system and scalability to constellation scale systems.

3. SYSTEM OVERVIEW

To provide background on the design of the system and mission that enable the described autonomous scheduling, a high level overview of the system is provided here. As previously stated, CogniSAT-6 is a 6U CubeSat. A CAD drawing of the system is shown in Figure 1. The spacecraft will be launched in a Sun Synchronous Orbit (SSO), at an orbital height of approximately 500 to 600 km.

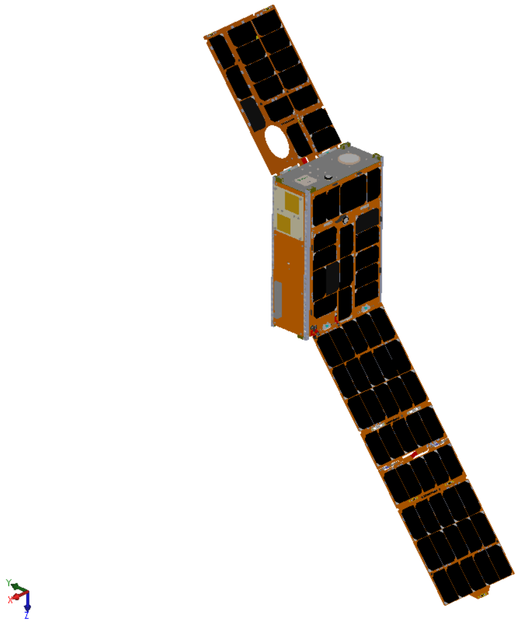

Figure 1. CAD drawing of CogniSAT-6.

The subsystems of the space segment of the system consist of: a high resolution hyperspectral imager, with a Ground Sampling Distance (GSD) of less than 5 meters during nominal image acquisitions, an OBC and an X- and S-band transceiver. In addition to these subsystems, the Ubotica CogniSAT-XE2 processing board (shown in Figure 2) and an Internet of Things (IoT) Inter Satellite Link (ISL) have been included in the system architecture.

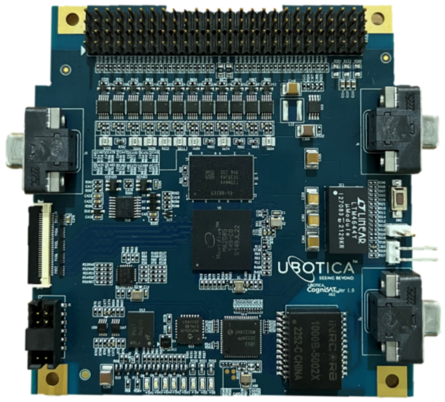

Figure 2. Engineering model of CogniSAT-XE2.

It is these subsystems that enable a myriad of new use cases among which is the autonomous operational scheduling described here. The Ubotica CogniSAT-XE2 board is a power efficient hardware accelerator that enables onboard processing of data using embedded Computer Vision (CV) and Image Signal Processing (ISP) pipelines as well as neural networks. The board features the Movidius Myriad X Vision Processing Unit (VPU), which provides powerful compute capabilities at a small Size Weight and Power (SWaP) form factor. Due to its low power requirements, CogniSAT-XE2 can run complex CV, ISP and AI pipelines at demanding duty cycles, even in a constrained environment such as a CubeSat. The Myriad X VPU has previously been used for demonstrating onboard AI applications on the International Space Station (ISS) [7].

A simplified system diagram for CogniSAT-6 is shown in Figure 3. Note that some subsystems, such as ADCS, EPS, etc., have been excluded here for the sake of clarity. As shown, the central functional block in the system is the OBC, which interfaces to the other subsystems in the functional flow. The processing of image data on board CogniSAT-6 is distributed between the OBC and CogniSAT-XE2. The preprocessing and geolocation of raw image data is performed on the OBC by dedicated and lightweight Ubotica software. After these steps are performed, raw image data is transferred in batches to the CogniSAT-XE2 over a high-speed Ethernet interface where inference is performed by the selected neural network. The output of the AI inference is transferred back to the OBC in batches, where these batches are postprocessed if required, concurrently to the ongoing inference operations. The end-to-end process is designed to take less than 3 minutes for a 400 km^2 acquisition, but can even be faster under certain circumstances.

The possible neural network applications are numerous, for example: cloud detection, detection of objects of interest such as ships, detection of natural disasters such as forest fires, environmental protection by detection of deforestation, etc. Furthermore, different neural networks may be used consecutively in a single pipeline. For instance, cloudy images can be discarded for further pro-

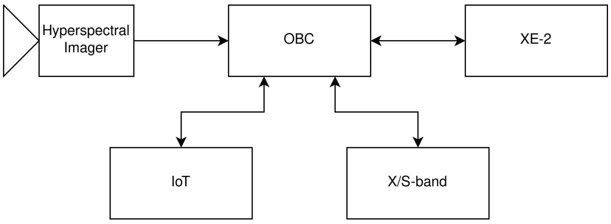

Figure 3. Simplified system diagram for the space segment of CogniSAT-6.

cessing by an object detector, or a detection of flooding can trigger processing by a life raft detection algorithm.

In addition to these AI-based data interpretation pipelines, the system architecture enables a range of novel operational capabilities. These capabilities include: tip-and-cue scenarios for constellations (where one spacecraft cues data acquisitions of other spacecraft), context-based autonomous system resource management (such as scheduling or cancelling new acquisitions), context-based autonomous adaptive system settings, triggering certain system modes, etc.

Since the ability to interpret data onboard is entirely implemented in software, a major advantage of the presented system architecture is its operational flexibility. The use case of the mission can be changed completely by executing a software update or calling a different application already present on the spacecraft. The functional blocks within the onboard data pipeline are designed such that they are fully modular. As an example, with one software update one could use the system to detect forest fires during forest fire season, and a month later the same hardware could be used to detect dark vessels by uploading a ship detector.

4. AUTONOMOUS SCHEDULING

One of the capabilities implemented on CogniSAT-6 is the autonomous scheduling of acquisitions based on the detection of features of interest without a ground station in the loop. A schematic of the functional flow of this concept is shown in Figure 4.

The concept of operations for this capability can be summarised as follows:

1. The spacecraft flies over a predefined region of interest
2. An image is captured at the scheduled location using the planned system state
3. The image is processed in real time on board the spacecraft to detect and subsequently geolocate features of interest (e.g., ships)

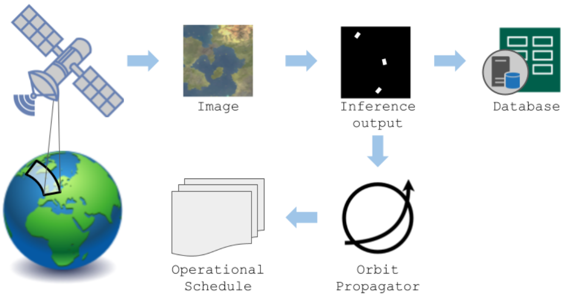

Figure 4. Functional flow for autonomous scheduling CONOP for CogniSAT-6.

4. If a feature of interest is found, results are stored and an orbit propagator is called. If no feature of interest is found, no action is taken and results are stored.
5. [Optional] If a feature of interest is found, this feature is send over the ISL directly to ground to inform mission control.
6. The propagator determines the next opportunity to capture the location of the feature of interest and the required spacecraft attitude.
7. A followup image acquisition is scheduled.
8. The followup image acquisition is executed.
9. [Optional] The followup image is processed in real time to detect and subsequently geolocate features of interest (e.g., ships)

The first demonstration of autonomous scheduling onboard CogniSAT-6 will utilise a ship detection application developed by Ubotica. The output of this application will consist of a geolocated location of detected ships in an Earth reference frame (longitude, latitude) as well as the length, width and direction of the detected ships and the confidence of the detection. During initial operations, only the location of the largest detected ship within one acquisition with a detection confidence of at least 80% will be passed to the orbit propagator to verify the end-to-end functionality. This is achieved by sorting the detected ships by area and thresholding for confidence. During later phases more elaborate acquisition logic is envisioned with more complex operational constraints. Examples are location based filtering (i.e., if a ship is within a certain monitoring area), ship orientation based filtering, ship concentration based filtering, etc.

The proposed system can also be extended to a tip-and-cue scenario, where the coordinates of the detected feature of interest are sent over an ISL to a trailing spacecraft. This spacecraft then utilises these coordinates as input for its onboard orbit propagator, cueing the acquisition of this location as soon as possible. Due to the modular nature of the proposed system, the developed pipeline can be readily uploaded to a compatible spacecraft to demonstrate this principle, provided the required subsystems are present.

5. DISCUSSION

By interpreting data on board the spacecraft, the amount of information provided by an EO space system to end users can be increased by up to an order of magnitude in storage- or downlink- constrained systems. This can be justified by a simple calculation. For example: roughly 60% of the Earth is covered by clouds. Cloudy acquisitions are not generally of interest to EO data users, hence statistically 40% of images returned to ground are of value. Removing cloudy images after capture thus increases the value generated by the space asset by 2.5x. Furthermore, if a particular feature is of specific interest (e.g., forest fires, ships etc.) and only 5% of acquisitions contain this feature, discarding the 95% of data not of value to the end user increases the value generated by the space asset by 20x.

By using autonomous scheduling (in combination with cloud detection), the value of follow up acquisitions for an end user is guaranteed. Even if the feature detected in the first acquisition is not present in the followup acquisition, knowing this fact is of value to the end user (e.g. a ship has moved, a fire has been extinguished, etc.).

Furthermore, this principle can be expanded to more complex logic. For example, sizes of features can be considered, specific locations of features, movement of features, etc. Utilising this level of analysis, even higher efficiency and higher return on investment for EO systems can be achieved.

The capabilities described in this paper will be verified and validated during an operational campaign over a number of months. During this operational campaign, a fixed number of areas of interest with a low likelihood of cloud cover and high likelihood of ships will be used. A list of large ports at statistically (near) cloud free geographical coordinates has been drawn up. Over the course of a series of months, data will be collected on the rate of successful and correct identifications of features of interest, the statistics and correctness of the autonomously scheduled acquisitions etc. This data will be analysed and published in future work.

6. CONCLUSION

The upcoming launch of the CogniSAT-6 commercial mission by Ubotica and Open Cosmos in Q1 2024 marks a significant advancement in EO systems. The integration of the CogniSAT-XE2 processing board, a hyperspectral imager, and an IoT communication system in a 6U CubeSat enables unprecedented operational capabilities. The system's ability to detect features of interest, such as ships or natural disasters, and autonomously make informed decisions on followup image acquisitions, demonstrates the potential for advanced and intelligent operations in space and increases the value generated by an EO space asset by up to an order of magnitude. While previous missions, such as EO-1 and OPS-SAT, have demonstrated elements of dynamic and automated operations, the CogniSAT-6 system takes it a step further by combining AI-based data interpretation, autonomous scheduling, and dynamically re-configurable software within a cost-effective and scalable CubeSat platform.

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