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Flight of Dynamic Targeting on CogniSAT-6 - Update

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Abstract

Dynamic targeting (DT) is a spacecraft autonomy concept in which lookahead sensor data is acquired and rapidly analyzed and used to drive subsequent observation. We describe the Low Earth Orbit application of this approach in which lookahead imagery is analyzed to detect clouds, thermal anomalies, or land use cases to drive higher quality near nadir imaging. Use cases for such a capability include: cloud avoidance, storm hunting, search for planetary boundary layer events, plume study, and beyond. The DT concept requires a lookahead sensor or agility to use a primary sensor in such a mode, edge computing to analyze images rapidly onboard, and a primary followup sensor. Additionally, an inter-satellite or low latency communications link can be leveraged for cross platform tasking. We describe implementation in progress to fly DT in late Spring 2025 on the CogniSAT-6 (Ubotica/Open Cosmos) spacecraft that launched in March 2024 on the SpaceX Transporter-10 launch.

Keywords: remote sensing, dynamic targeting, intelligent sensing, edge computing, artificial intelligence, spacecraft autonomy

1. Introduction

Rapid developments in New Space are enabling new paradigms for Earth Observation. Decreased launch and spacecraft costs are driving an explosion in the number of Earth Observation assets. Advances in hardware, increased risk tolerance (in part due to decreased launch and hardware costs), and nascent communications infrastructure enable new strategies for Earth Observation that leverage "edge intelligence" enabled immediate processing of raw imagery into knowledge that can then be rapidly acted upon by the observing asset or rapidly transmitted to other entities for action. Intelligent networked space assets are envisioned by NASA's Earth Science Technology Office (ESTO) New Observing Strategies (NOS) [1] as well as the European Space Agency's Phi-Lab [2].

In this paper, we describe an effort to demonstrate in-space extremely rapid application of edge intelligence, Dynamic Targeting [3] (DT) to the Low Earth Orbit (LEO) case. DT LEO looks ahead in the orbital track and analyzes this data on the fly for near nadir observation enhancement. At an orbital altitude of 500 km and a ground speed of approximately 7.5 km/s a 45 degree lookahead results in a lookahead of approximately 74 seconds before nadir [4]. Figure 1 below shows the sequence of activities in the timeline for the DT concept.

We are working to implement DT onboard the CogniSAT-6 (CS-6) [5] spacecraft. CS-6 launched in March 2024 on Transporter-10 from Vandenberg Space Force Base in California, USA. CS-6 DT has only a single imager and therefore uses the CS-6 instrument (utilizing red, green, blue, and very near infrared spectral bands) as both the lookahead and primary sensor. Onboard algorithms for analysis will use the Intel Myriad X edge processor onboard for both deep learned convolutional neural networks and for implementations of spectral analysis including: spectral angle mapping, match filters, and spectral unmixing. Several lookahead analysis techniques are planned [6,7] including: cloud detection/avoidance, thermal anomaly detection (for detection of volcanic activity or wildfires), and spectral signature detection. The CS-6 orbit allows for a 60-90 seconds lookahead lead time using a 40-50 degree lookahead. The current effort plans in-space demonstration of DT in early 2025 and we report on the status of implementation for that scheduled flight time.

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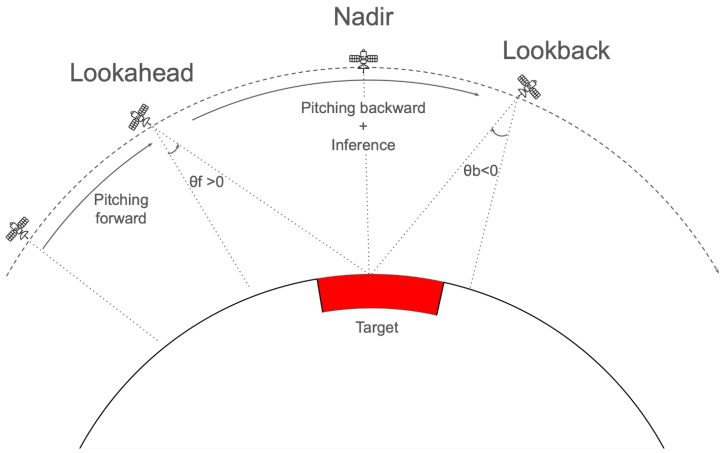

Figure 1: Dynamic targeting on CogniSAT-6. A single instrument will be used to both acquire a lookahead image and a near-nadir targeted image.

DT has numerous applications. The most prevalent use case is for cloud avoidance as many instruments and science are hampered by clouds. DT for cloud avoidance is already being used in operations of the TANSO-FTS-2 sensor on the GOSAT-2 spacecraft [8] quite effectively by JAXA. In this application a lookahead visible range sensor is used to detect cloud obscuration and the primary TANSO-FTS-2 Fourier Transform Spectrometer is targeted to avoid detected clouds resulting in more usable science data. Additional studies have analyzed the productivity gains from cloud avoidance for atmospheric retrievals such as CO_2 and CH_4 [9,10] as well as more generic studies [3].

Mission concepts to use DT to hunt for rare science events of interest also show promise. The SMICES Smart Ice Storm Hunting Radar would use DT to hunt for deep convective ice storms with a profiling radar [11]. Other concepts would use DT to target specialized radar and lidar to capture rare, transient Planetary Boundary Layer (PBL) phenomena [12].

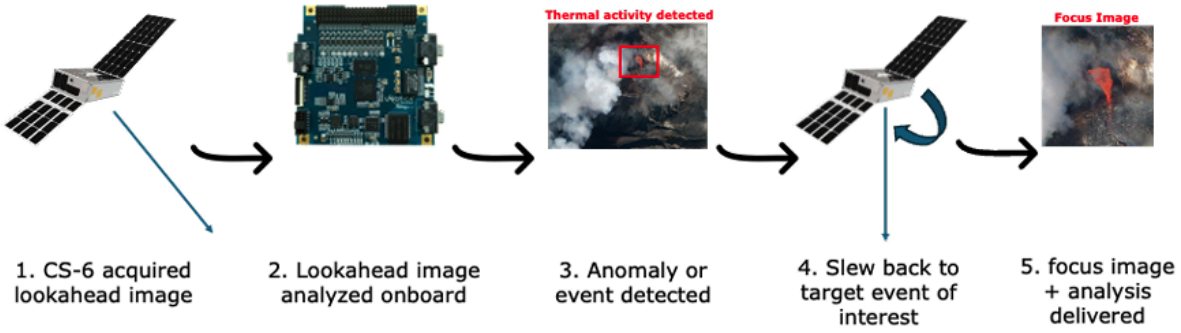

Figure 2: Overview of a dynamic targeting workflow for volcano monitoring.
Image sources: Ubotica Technologies (steps 1, 2, & 4), Planet Labs (step 3 and 5).

2. Execution Timeline

The challenge in implementing DT is to meet the execution timeline dictated by LEO orbital velocity. As indicated, at a 500 km orbital altitude, a 40, 45, and 50 degree lookahead produce timelines from lookahead imaging to nadir view of 60 to 90 seconds. Within this timeframe all of the actions indicated below in Figure 3 must be performed.

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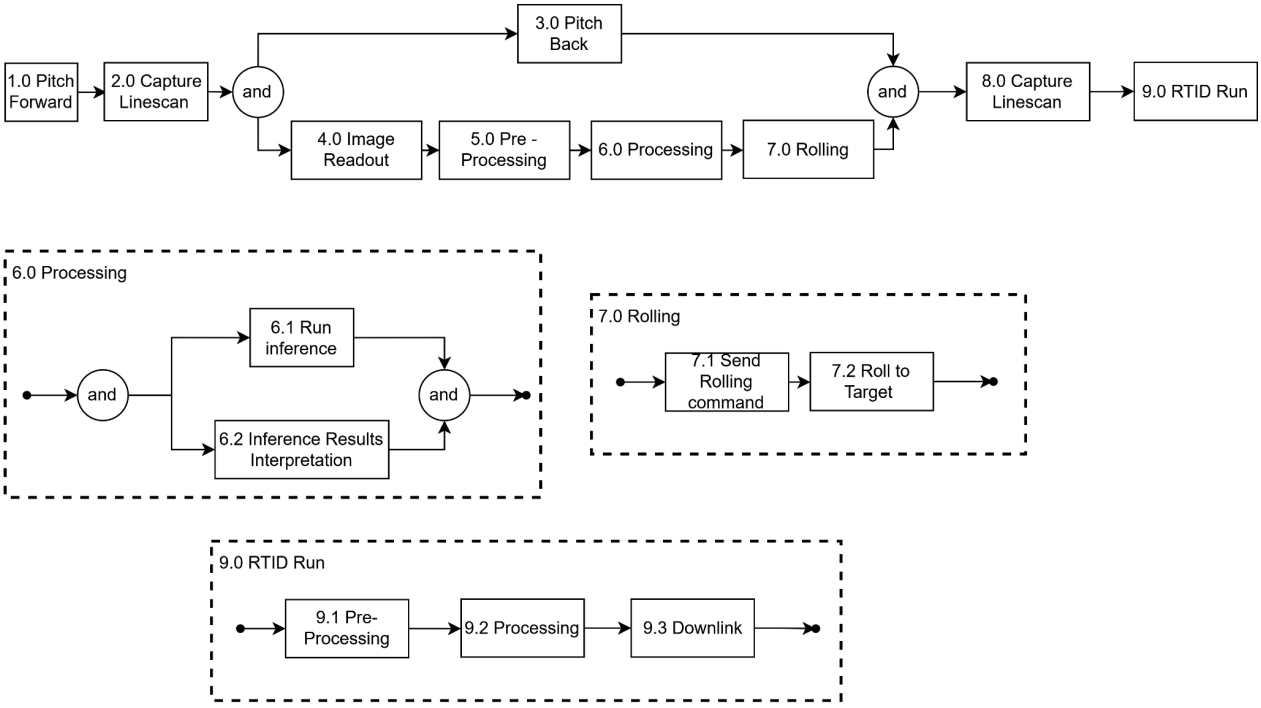

Figure 3: The functional flow for executing dynamic targeting. After a lookahead image is acquired it will be processed in parallel as the spacecraft pitches the primary sensor towards nadir.

Many options are available in the lookahead imaging. Because CS-6 does not have a dedicated lookahead imager the primary imager does not have a large field of view. One strategy is to emulate a larger field of view coarser spatial resolution imager by smearing the pixels by executing slews across track or by reducing readout times to in effect produce larger pixels along track.

Transferring the image out of the instrument to the processing unit can take considerable time as CS-6 was not designed for the rapid instrument readout required for DT. In normal satellite operations instrument readout times of minutes are not an issue however for the DT concept readout times in the seconds are more suited for the DT timeline. In order to reduce readout time we are investigating decimation of the data (e.g. sampling only a subset of the pixels, in effect simulating a lower spatial resolution instrument), reading out only a subset of the spectral bands (or using the panchromatic band).

Also to improve the accuracy of the image analysis, we perform simple dynamic range stretching of the image as a substitute for more sophisticated radiometric correction or conversion to top of the atmosphere radiance or reflectance.

Lookahead image analysis in principle could use almost any image analysis technique [6,7]. For practical purposes our primary three lookahead algorithms are: cloud avoidance, cloud seeking (as a SMICES or PBL surrogate), and thermal anomaly detection (as a surrogate for volcano or wildfire thermal search).

As one of the most time consuming operations in the DT timeline is the slew from lookahead to near nadir mode (this is a slew of 40-50 degrees along track), to optimize the timeline this slew can be initiated prior to completion of the lookahead image analysis. In an ideal situation, a lookahead sensor makes this slew unnecessary.

For nadir image analysis, we enable the full complement of onboard techniques we are implementing for the CS-6 sensor [6,7]. Also for a subset of the DT sequences we will also downlink the nadir analyses using the intersatellite link to highlight the rapid product delivery enabled by this technology.

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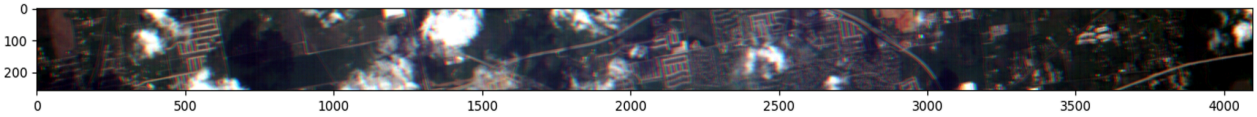
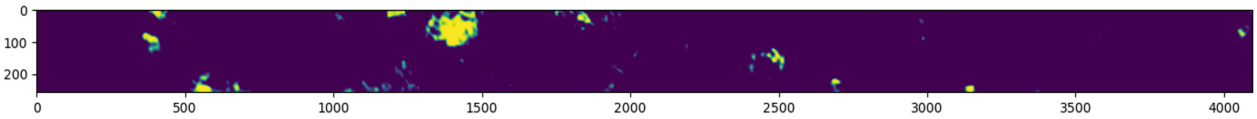
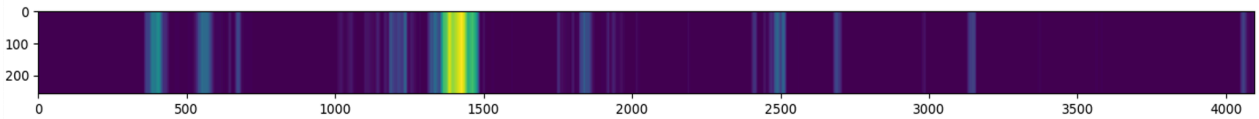
The roll angle is selected based on the image analysis of the lookahead scene. Figure 4 illustrates the computation to go from lookahead scene to a roll angle for the cloud avoidance application. Using a convolutional neural network, the input image (top) is segmented to identify clouds (second to top). This two dimensional cloud mask is collapsed to a one dimensional array by averaging pixels along the track (second to bottom). Finally, we select the fixed window of pixels along the swath with the lowest cumulative cloud values (bottom). The fixed window we observe is mapped to a roll angle that is precomputed on the ground based on the overflight and the rotation of the Earth. This whole algorithm must execute within 6 seconds.



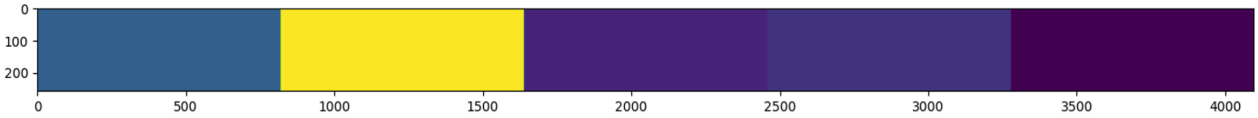
(a) Illustrative "notional" Lookahead image. *Includes imagery from CogniSAT-6/HAMMER, 2025, Ubotica. All rights reserved.*



(b) cloud classifier run on (a) - yellow indicates identified clouds



(c) summarised across track cloud pixels from (b) - yellow indicates cloudiest across track locations



(d) fixed window summarization across track from (c) (brightest = most clouds, darkest = least clouds)

Figure 4: Illustration of the image analysis algorithm for dynamic targeting on CogniSAT-6.

4. Status

Flight of DT on CS-6 is currently in implementation. Several types of onboard imagery analysis flew in Fall 2024 [6,7] but not in DT mode (See below Figure 5). Slewing tests to assess feasibility were performed on multiple spacecraft indicating that CS-6 has sufficient agility for the DT scenario using the sensor as both lookahead and nadir sensor. Timing benchmarks have been performed that indicate excellent progress in developing a processing pipeline that will execute onboard within the hard timing constraints enforced by orbital geometry and spacecraft capability. This implementation is undergoing testing as this paper goes to press with an anticipated first flight test in May 2025.

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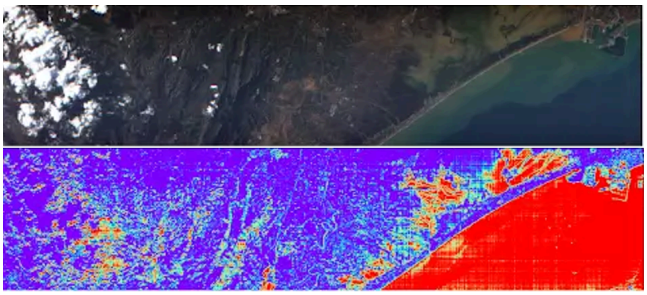
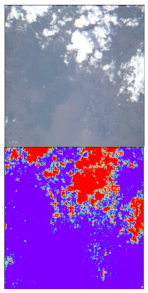


(a) Valencia, Spain, 11/02/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for surface water extent with red indicating water and purple indicating non-water. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*



(b). Ulsan, South Korea, 10/27/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for cloud detection with red indicating clouds and purple indicating non-clouds. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*

Figure 5: Sample image analysis from onboard executions.

In parallel, we are also exploring a new concept in which rather than using a sensor on the same spacecraft for lookahead data streamed from a weather satellite is received by the targeting spacecraft and exploited for targeting or sensor reconfiguration [13].

5. Conclusion

Advances in spacecraft edge computing offer tremendous potential for onboard data analysis to improve spacecraft operations. Dynamic Targeting (DT) represents an extreme edge case where a spacecraft acquires data, analyzes said data onboard, and uses that analysis to improve further remote sensing, all within a single orbital overflight. In LEO these timelines can be 30-60 seconds for an orbital altitude of 500 km, a lookahead of 45-50 degrees, and an orbital velocity of approximately 7.5 km/s.

We describe efforts to fly DT on the CogniSAT-6 spacecraft in Low Earth Orbit. The concept has been analyzed and is in implementation for flight in May 2025. Flight demonstration of DT will pave the way for future highly autonomous Earth and deep space missions to more effectively observe rare, transient phenomena.

Acknowledgements

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