Appears in Proceedings of 18th Symposium on Advanced Space Technologies in Robotics and Automation, Leiden, NL, October 2025. JPL Clearances: CL-25-3388, URS333141.
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DYNAMIC TARGETING - FLIGHT REPORT

Steve Chien [1*], Itai Zilberstein[1], Alberto Candela[1], Domenico Barretta[1,4], David Rijlaarsdam[2], Tom Hendrix[2], Aubrey Dunne[2], Amaury Perrocheau[2], Cristopher Castro Traba[2], Oriol Cortes Grau[3], Alexandre Gol i Mestre[3], Manel Pedra Bové[3], Oriol Aragon[3], Juan Puig Miquel[3]

[1] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*
[2] *Ubotica, Dublin, Ireland*
[3] *Open Cosmos, Harwell, UK*
[4] *University of Campania, Naples, Italy*

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 by the same spacecraft. We describe flight of the Low Earth Orbit (LEO) application of DT - in which lookahead imagery is analyzed to detect clouds, thermal anomalies, or land use cases to drive higher quality near nadir imaging in a single overflight. 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: (1) a lookahead sensor or agility to use a primary sensor lookahead mode; (2) edge computing to analyze images rapidly onboard; and (3) a primary followup sensor. Additionally, an intersatellite or low latency communications link can be leveraged for rapid alerts or cross platform tasking. We describe successful demonstration of DT on the CogniSAT-6 (Ubotica/Open Cosmos) spacecraft in the summer of 2025 - detailing several engineering challenges.

Key words: spacecraft autonomy, robotic autonomy, astrobiology.

1. INTRODUCTION

In this paper, we describe flight of rapid application of edge intelligence - Dynamic Targeting (DT) [1] to the Low Earth Orbit (LEO) case. DT LEO looks ahead in the orbital track and analyzes this data on the fly to enhance near nadir observation. 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 and a 50 degree lookahead results in a lookahead of approximately 90 seconds [4]. Figure 1 shows the spacecraft lookahead and nadir collect positions in a single overflight execution of the DT concept. Figure 2 shows the image processing sequence of activities in the timeline for the DT concept.

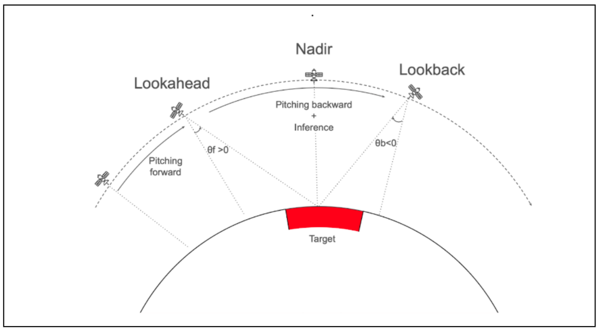

Figure 1. Dynamic targeting on CogniSAT-6. A single instrument will be used to both acquire a lookahead image and a near-nadir targeted image.

We have implemented DT onboard the CogniSAT-6 (CS-6) [11] spacecraft, 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 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. Cloud detection and avoidance has flown and several additional applications may be flown on future flights [5, 14] including: storm seeking, 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. Current in space demonstration of DT has been flying July-August 2025 with additional flights planned in August and September 2025 .

DT has numerous applications - for pointers to these applications see [3]. DT is in operational use on the [12]

*Corresponding author: steve.a.chien@jpl.nasa.gov.

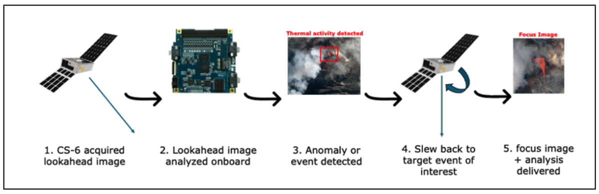

Figure 2. Overview of a dynamic targeting workflow for volcano monitoring. Image sources: Ubotica Technologies (steps 1, 2, 4), Planet Labs (step 3 and 5).

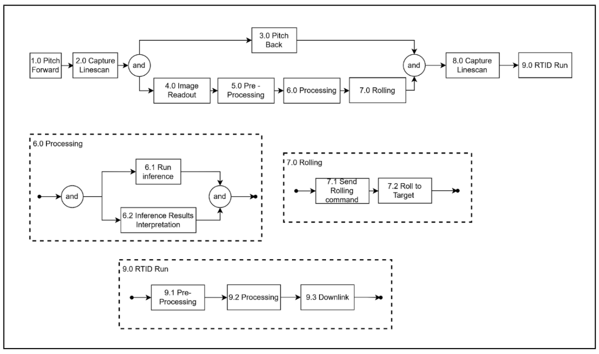

Figure 3. The functional flow for executing dynamic targeting. After a lookahead image is acquired it will be processed in parallel as the spacecraft pitches the primary sensor towards nadir.

fo the TANSO-FTS-2 instrument on GO-SAT-2 for cloud avoidance and has been studied for a range of topics including hunting for deep convective ice storms [13], cloud avoidance [1, 10, 8], and planetary boundary layer [2].

2. ENGINEERING CHALLENGES

2.1. Execution Timeline

The primary 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 in Figure 3 must be performed.

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 and most spacecraft are not designed for the rapid instrument readout required for DT. In order to reduce readout time on CS-6 we extract only 3 bands from the 32 spectral bands accessible by the instrument.

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.

2.2. Lookahead Imaging

Lookahead imaging introduced two issues - spectral band alignment and pointing.

One issue is that lookahead of 50 degrees was not anticipated as part of the normal operations for CogniSAT-6 nor prior Open Cosmos spacecraft. Early tests showed a significant spectral band misalignment issue where initial classifiers used several spectral bands to perform classification. This band misalignment is likely due to readout timing and spatial projection issues along track caused by the extreme (50 degrees) off nadir angle exacerbated by grazing angle issues caused by the Earths curvature. In order to address these issues: (1) a classifier was made using the panchromatic band; and (2) a model of the band misalignment was created and used to develop an algorithm for dynamic setting of the image acquisition parameters to mitigate the band alignment problem. The panchromatic band classifier performed adequately and is being used for current tests. The band re-alignment algorithm performs adequately but is an area for future work.

2.3. Earth's rotation Lookahead to Nadir

A second issue relating to lookahead is that if the spacecraft pitches directly ahead along track the lookahead footprint is not what a nadir acquisition will observe.

Figure 4. Notional image processing of the lookahead image to drive nadir acquisition targeting. Raw imagery credit Ubotica/Open Cosmos.

This is because in the 90 seconds between lookahead and nadir acquisitions the Earth will have rotated by a potentially significant amount based on the exact angle (e.g. compass angle) of the ground track and the latitude (how close to the equator) of the acquisition. Because most CogniSAT-6 acquisitions are on the descending node of the orbit, the spacecraft is flying in a generally southerly direction and the Earth's rotation is from west to east therefore the lookahead imaged location will have rotated eastwards (e.g. from the spacecraft perspective from starboard to port) in the time between the lookahead and near-nadir acquisition. The Earth's rotation has a maximum surface velocity of approximately 465 m/s at the equator resulting in an effect of up to 41.85 km for a direct N/S trajectory. Using knowledge of the location (lat/lon) of the observation and the orbit ground track we pre calculate the roll angle offset to account for the Earth's rotation in between the lookahead and near nadir acquisitions. Alternatively we could have canted the lookahead image to the starboard (right) so that it more closely aligned with the nadir track however that would have increased footprint distortion (which already occurs due to the Earth's curvature).

The roll angle is selected based on the image analysis of the lookahead scene. Figure 4 illustrates the image processing computation to go from the 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. Figure 5 shows the lookahead imagery and near nadir collect acquired from a DT run in July over Brazil, South America.

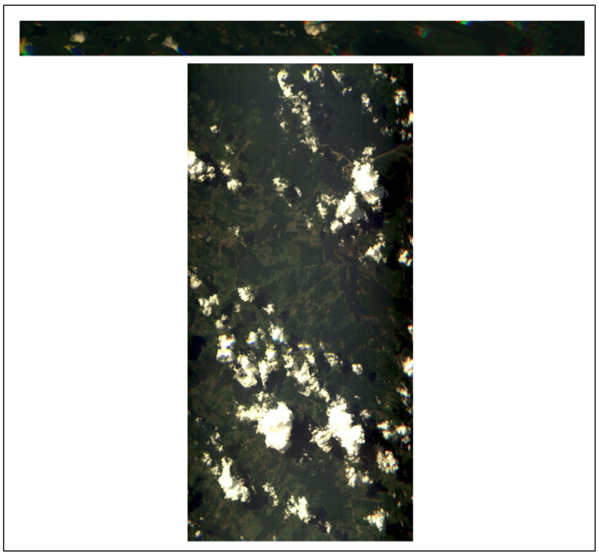

Figure 5. Imagery from the DT flight of 17 July 2025 acquisition over Brazil, South America. Lookahead imagery at top, nadir collect at bottom. Raw imagery credit Ubotica.

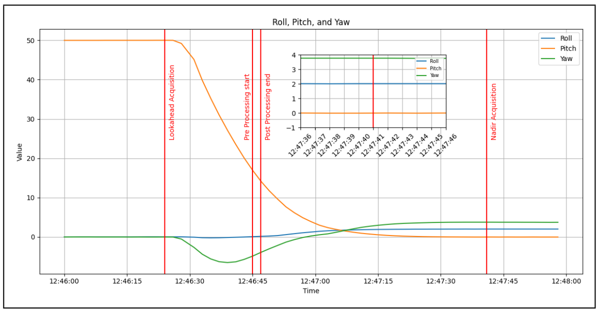

Figure 6. Attitude profile for successful DT run on CogniSAT-6. This run was performed over Democratic Republic of Congo 01 August 2025. The graphs show additional margin for reducing the lookahead angle.

3. CURRENT STATUS, FUTURE WORK AND CONCLUSIONS

As of 29 August 2025, a total of 8 DT flight tests have been executed with more scenes planned.

Figure 6 shows the attitude and control system (AACS) position curves while performing the DT acquisition of Democratic Republic of Congo on 01 August 2025. The curves show ADCS reaching the nadir target orientation quickly in 60-70 seconds. While additional time must be allocated for settling this indicates that it is likely feasible to reduce the lookahead time to 60 seconds and commensurately the lookahead angle to roughly 45 degrees. Using a smaller lookahead angle will result in higher quality data to drive nadir targeting.

Future work includes a range of topics:

- reduce lookahead angle by reducing operational margins;
- improve precision of target roll angle determination;
- test snapshot lookahead image under moving pitch-back maneuver to further decrease lookahead angle
- improve band alignment for lookahead imagery;
- demonstrate lookahead imagery not directly ahead of the spacecraft;
- executing a wider range of classifiers and DT scenarios;
- investigate alternate responses such as a stare at the target area; and
- demonstration on additional space platforms including as part of distributed multi-spacecraft coordination [6].

Alternative lookahead data could be considered. Direct intercept of higher altitude weather satellite data is one option [7]. Another option is to use data from geostationary weather satellites and intersatellite link to perform ”just in time” commanding [9].

We have described implementation of DT in Low Earth Orbit on CogniSAT-6 - a 6U cubesat without a dedicated lookahead sensor. Numerous on orbit tests have resulted in successful demonstration of DT. Several engineering issues were encountered including onboard processing and data transfer times, band misalignment in lookahead imagery, and handling of the Earth's rotation between looahead and nadir imaging. Successful demonstration of DT matures this valuable autonomous capability for future missions.

ACKNOWLEDGMENTS

Portions of this research was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004). Distributed 2025 CC BY-NC-ND 4.0.

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