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Software-Driven Imaging Mission Planning and Attitude Control for Super-Agile Satellite

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ABSTRACT

This study evaluates multitarget imaging within a single orbital pass using a software-driven 6U CubeSat simulation. Advances in software-defined operations have enabled small Earth observation satellites to perform imaging tasks beyond their hardware limitations. Leveraging this capability, a simulation was developed using the Systems Tool Kit (STK) to assess agile imaging performance. Six observation sites in the Eastern Province of Saudi Arabia were selected to evaluate the effectiveness of dynamic, software-driven attitude planning. By integrating access analysis with a multi-segment mission plan, the satellite executes rapid attitude maneuvers to sequentially align the onboard sensor with each target. The results demonstrate that the proposed strategy successfully acquires six spatially distributed targets within a single orbital pass, achieving a six-fold increase in coverage compared with conventional nadir-pointing operation. The required maneuvers remain within the operational limits of typical commercial 6U CubeSat attitude determination and control systems (ADCS), with peak slew rates below 8°/s. This study validates the feasibility of software-driven agile imaging through high fidelity simulation and highlights the potential of software-defined mission planning to enhance Earth observation performance without hardware modification.

Keywords: agile imaging, 6u cubesat, earth observation, multi-target acquisition, attitude control, systems tool kit

1. INTRODUCTION

Earth observation (EO) is an essential component of modern scientific, environmental, and strategic decision-making. Nations increasingly rely on timely satellite imagery to support applications ranging from climate and environmental monitoring to infrastructure planning, disaster response, and national security operations. As global urbanization accelerates and climate-driven risks intensify, the demand for high-frequency multiregion imaging has increased dramatically [1]. Although improvements in sensor resolution and onboard processing have advanced the field of EO, the key challenge now lies in achieving rapid revisits, expanded area coverage, and flexible imaging using cost-efficient satellite systems.

Historically, EO systems have been dominated by large satellites [2] equipped with wide-swath imaging payloads and multi-satellite constellations designed to deliver consistent temporal coverage. Sentinel-2, for instance, achieves a five-day revisit at medium spatial resolution using a twin-spacecraft architecture [3]. Commercial operators such as Planet Scope perform daily global imaging by deploying dozens of small satellites arranged in coordinated constellations [4,5]. While these systems offer excellent operational performances, their high manufacturing costs, complex deployment requirements, and large-scale ground infrastructure render them inaccessible to many institutions, particularly emerging space programs or region-specific missions.

The abovementioned limitations have encouraged a shift toward smaller platforms, particularly CubeSats, owing to their low cost, rapid development cycles, and adaptability. However, small satellites face fundamental constraints such as a limited optical aperture, narrow native swath, reduced signal-to-noise ratio, and restricted power availability for continuous imaging [6]. A single 6U CubeSat equipped with a typical narrow-swath payload can only revisit a mid-latitude region every 15–30 days when operated in a purely nadir-pointing mode [7]. Such revisit intervals are insufficient for regions with fast-changing surface conditions or high monitoring needs, such as the Kingdom of Saudi Arabia, where rapid urban development, coastal expansion, and Vision 2030 environmental initiatives demand more frequent imaging of targeted areas [8].

To overcome these limitations, without increasing the number of satellites or modifying the payload hardware, recent research introduced the concept of agile imaging, which exploits the attitude control capabilities of a satellite to dynamically repoint its line of sight during a single orbital pass. Critical studies have demonstrated that off-nadir slewing enables multi-strip imaging, thereby virtually expanding the effective swath width beyond the physical limits of the onboard imager [9]. Controlled attitude maneuvers allow a CubeSat to image adjacent or spatially separated regions in a rapid sequence and can increase the number of targets imaged per pass, as demonstrated in this study [8,10]. However, agile maneuvers also introduce engineering challenges, such as increased geometric distortions, a higher risk of motion blur, increased attitude settling times, and non-uniform ground sampling[11]. A proper mission design must balance agility, viewing geometry, sensor limitations, and image stability.

The Ansys Systems Tool Kit (STK), developed by Ansys, Inc. (Pennsylvania, USA) has emerged as one of the most capable platforms for modeling high-fidelity EO missions. STK enables precise access window analysis, sensor geometry modeling, and multisegment attitude scheduling[12]. In addition, it allows analysts to validate the feasibility of rapid re-targeting sequences by simulating realistic slew rates, stabilization times, and imaging durations for small-satellite attitude determination and control systems (ADCSs).

Building on these advancements, this study investigates a software-driven agile imaging mission for a 6U CubeSat operating over the Eastern Province of Saudi Arabia. A set of geographically distributed targets was selected to represent practical, multi-interest observation points within a densely populated urban corridor. This study aims to evaluate whether a single 6U satellite can acquire all six targets within a single orbital pass through appropriately sequenced attitude commands. The results confirm the system-level feasibility of software-driven, time-tagged agile imaging by a single 6U CubeSat by integrating access analysis, attitude maneuver planning, and execution timeline verification to enable multi-target acquisition within a single orbital pass.

The satellite mission planning workflow consists of three integrated phases: (1) time-window analysis, (2) multi-segment attitude scheduling, and (3) simulation and feasibility verification.

(1) Window Analysis
STK is used to compute the visibility intervals between the CubeSat sensor and each target, identifying when each target becomes observable and establishing the temporal foundation for constructing the imaging sequence.

(2) Multi-Segment Attitude Scheduling
A time-tagged mission plan is created, in which the satellite transitions between targets using rapid but feasible slews. Each segment specifies the target name, start time, pointing command, and dwell duration. This mirrors real operational behavior, where precise time-stamped commands are uplinked to the onboard computer for execution.

(3) Simulation and Feasibility Verification
The full mission was executed in the high-fidelity 3D environment of STK to verify pointing performance, ensure target alignment, and assess whether attitude transitions satisfy realistic ADCS limits for a 6U CubeSat platform.

Through this workflow, this study demonstrates that software-defined imaging strategies can substantially expand the effective coverage of a single 6U satellite. By leveraging agile attitude maneuvers and optimized scheduling, a satellite can image multiple spatially separated targets in a single pass, achieving performance previously associated with larger satellites or multi-satellite constellations. This provides a compelling pathway for regional EO missions in Saudi Arabia, where flexible and frequent observations are essential for environmental, developmental, and strategic decision making.

2. BACKGROUND, MOTIVATION, AND OBJECTIVES

2.1. Background and Motivation.

A 6U CubeSat with a narrow-swath optical payload is often unable to observe multiple geographically-separated targets during a single orbital pass. In this study, the region of interest consisted of six distributed urban locations in the Eastern Province of Saudi Arabia, which spans a large geographical area of approximately 529,000 km^2, extending significantly in both the east–west and north–south directions.

Under conventional nadir-pointing operations, these targets would typically require multiple passes to be observed, reducing the temporal responsiveness of applications that require timely regional monitoring. Because the platform is constrained by volume, mass, power, and thermal limitations, increasing coverage through larger optics or additional payload hardware is not practical. Therefore, this study adopts a software-driven approach in which the spacecraft attitude is actively repointed to sequentially

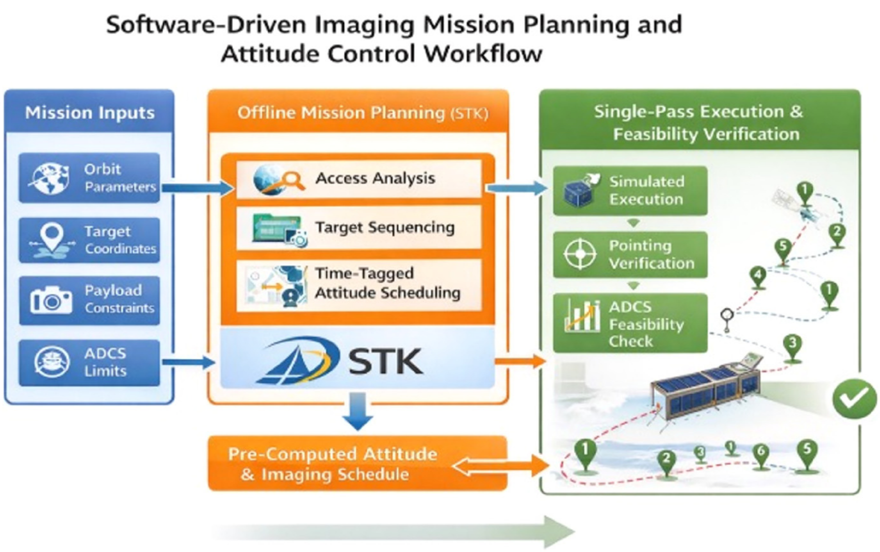

Figure 1. Software-driven agile imaging mission planning workflow showing mission inputs, STK-based access analysis and time-tagged attitude scheduling, and single-pass execution feasibility verification

image multiple targets during one pass. The objective is not to change the payload itself but to improve the mission performance through time-tagged attitude planning.

Moreover, this study validated whether such a multitarget imaging sequence could be executed within realistic 6U CubeSat operational limits. Using STK, the access windows, target visibility, maneuver timing, and attitude transitions were analyzed to verify whether all selected targets could be observed in a single pass while maintaining a feasible slew rate and pointing requirements. Unlike studies that primarily focus on optimization algorithms for target scheduling, this study emphasizes system-level feasibility. Consequently, this study confirms that software-driven agile imaging can be implemented as a practical mission concept for a 6U CubeSat using realistic timing, geometry, and ADCS constraints.

2.2. 6U CubeSat Mission Objectives. The core mission objective is to minimize the effective revisit time over an elongated region of interest (ROI) by expanding the coverage through agile multi-directional imaging and forward motion compensation (FMC). Instead of waiting for multiple orbital cycles, the attitude system is leveraged to command time-tagged pointing maneuvers that allow a spacecraft to image multiple strips or discrete targets during a single orbital pass.

Formally, the objective can be expressed as:

$$MinimizeT_{(revisit)} = \frac{A_t}{W_{eff} * V_g} \tag{1}$$

where A_t is the total area of the region of interest, W_{eff} is the effective swath width after multistrip imaging, and V_g is the ground track velocity. This equation captures the relationship between imaging coverage and revisit performance by modeling how an increased effective swath width reduces the time required to observe the ROI.

Note that Eq. 1 represents a first-order approximation. A rigorous revisit time analysis requires the modeling of orbital repeat cycles, Earth rotation, access geometry, and multipass coverage accumulation. However, the objective of this study is not to derive a precise orbital revisit model, but to demonstrate how software-driven attitude agility increases W_{eff}, thereby reducing the revisit time at the system level. Thus, this simplified equation was used to support the mission design concept and provide intuitive insights into the performance improvement achieved through agile imaging. For a single-pass agile imaging scenario, an effective revisit reduction can also be interpreted as an increase in instantaneous coverage, rather than a change in orbital periodicity.

Accordingly, because the native swath width (W = 20.3 km) was insufficient, the mission sought to increase W_{eff} using agile pointing. Therefore, the mission optimizes (1) spacecraft attitude transitions, (2) exposure timing, (3) pointing stability, and (4) FMC stabilization while respecting all constraints to ensure safe and reliable operations.

3. SATELLITE MISSION WORKFLOW AND PAYLOAD SPECIFICATIONS

3.1. Mission Workflow. The workflow adopted in this study is illustrated in Figure 1. It is important to note that the imaging sequence in this study was constructed directly from the access windows obtained through STK analysis rather than through an automated optimization algorithm. The ordering of the targets follows their temporal visibility while ensuring feasible attitude transitions between consecutive imaging events. This approach reflects realistic operational practices, in which mission planners generate time-tagged command sequences based on geometric access constraints and system limitations. This study validates the feasibility of such a sequence under practical conditions rather than optimizing the scheduling performance.

Table 1. *Mission Execution Pattern*

Orbital Parameter	Value
Semimajor axis	6903 km
Altitude	525 km
Inclination	96.77°
Eccentricity	0
RAAN	85
Argument of Perigee	0

The satellite mission inputs, including the orbital parameters, target coordinates, payload characteristics, and ADCS constraints, are first processed through offline mission planning in STK to perform access analysis, target sequencing, and time-tagged attitude scheduling. The resulting precomputed mission timeline was then executed in the simulation to verify the single-pass feasibility and compliance with the spacecraft pointing and slew-rate limits.

3.2. Orbit and Imaging Specifications. The satellite operates in a near-circular low-earth orbit (LEO) with characteristics summarized in Table 1. This orbit is typical of Sun-synchronous regimes, enabling consistent lighting conditions and repeatable ground-track geometry. A visualization of the satellite's orbital pass is shown in Figure 2.

The imaging sensor used in this study was based on a representative commercial CubeSat-class Earth-observation payload with specifications consistent with those of the HyperScape100 hyperspectral imager (Simera Sense, South Africa)[14,15]. The assumed sensor characteristics are summarized as follows:

Linear push-broom imaging sensors rely on precise knowledge of the satellite ephemeris and attitude to achieve an accurate ground projection. The sensitivity of push broom imaging geometry to attitude and orbit uncertainties has been extensively analyzed in earlier high-resolution missions, demonstrating

Table 2. *Representative CubeSat Imaging Payload Specifications*

Parameter	Value
Optical configuration	Push broom
Focal length	580 mm
Aperture	95 mm
Field of view	2.22°
Detector	CMOS, 4096 pixels
Pixel size	5.5 µm
Radiometric depth	12-bit

the importance of accurate physical sensor modeling for image quality and geolocation accuracy[4]. This payload configuration is representative of modern CubeSat-compatible EO cameras and was used to approximate the imaging footprint, resolution, and attitude maneuver requirements during the simulation.

3.3. Payload Description.

The optical payload features are summarized below:

- GSD: 4.75 m, suitable for regional mapping
- Native swath: 20 km
- Optics: 95 mm aperture, 580 mm focal length
- Detector: 4096-pixel CMOS line array, 5.5 µm pixel pitch
- Dynamic range: 12-bit
- Spectral bands: 32 VNIR bands + optional panchromatic
- Mass: 1.1–1.3 kg
- Power usage: 5–8 W
- Internal storage: 128 GB

Although highly -performing for its class, the payload's swath limitations motivate the adoption of agile pointing to cover wider scenes. A representative photo of the CubeSat optical payload is shown in Figure 3.

4. SATELLITE MISSION PLANNING

4.1. Problem Formulation.

4.1.1. Expanded optimization statement.

The CubeSat mission's optimization task involves maximizing effective imaging coverage under operational constraints.

4.1.2. Goal.

The objective of the mission was to minimize the effective revisit time $(T\_revisit)$ by increasing the effective imaging swath achievable within a single orbital pass.

4.2. Mission Constraints.

The mission constraints are summarized below:

1. ADCS Power Constraint

$$P_{ADCS}(t) \leq P_{max}$$

2. Slew Rate Constraint

$$\omega\_sat(t) \leq \omega_{limit}$$

3. Image Quality Constraint (MTF Preservation)

$$MTF_{actual} \geq MTF_{min}$$

4. Pointing Stability Constraint

$$\sigma_{pointing} \leq \sigma_{allowed}$$

5. Exposure Timing Constraint

$$t_{exp} \leq t_{FMC-corrected}$$

6. Thermal and Power Budget Constraints

Because attitude slews require demand significant ADCS effort, the duty cycle is constrained by the available energy per orbit.

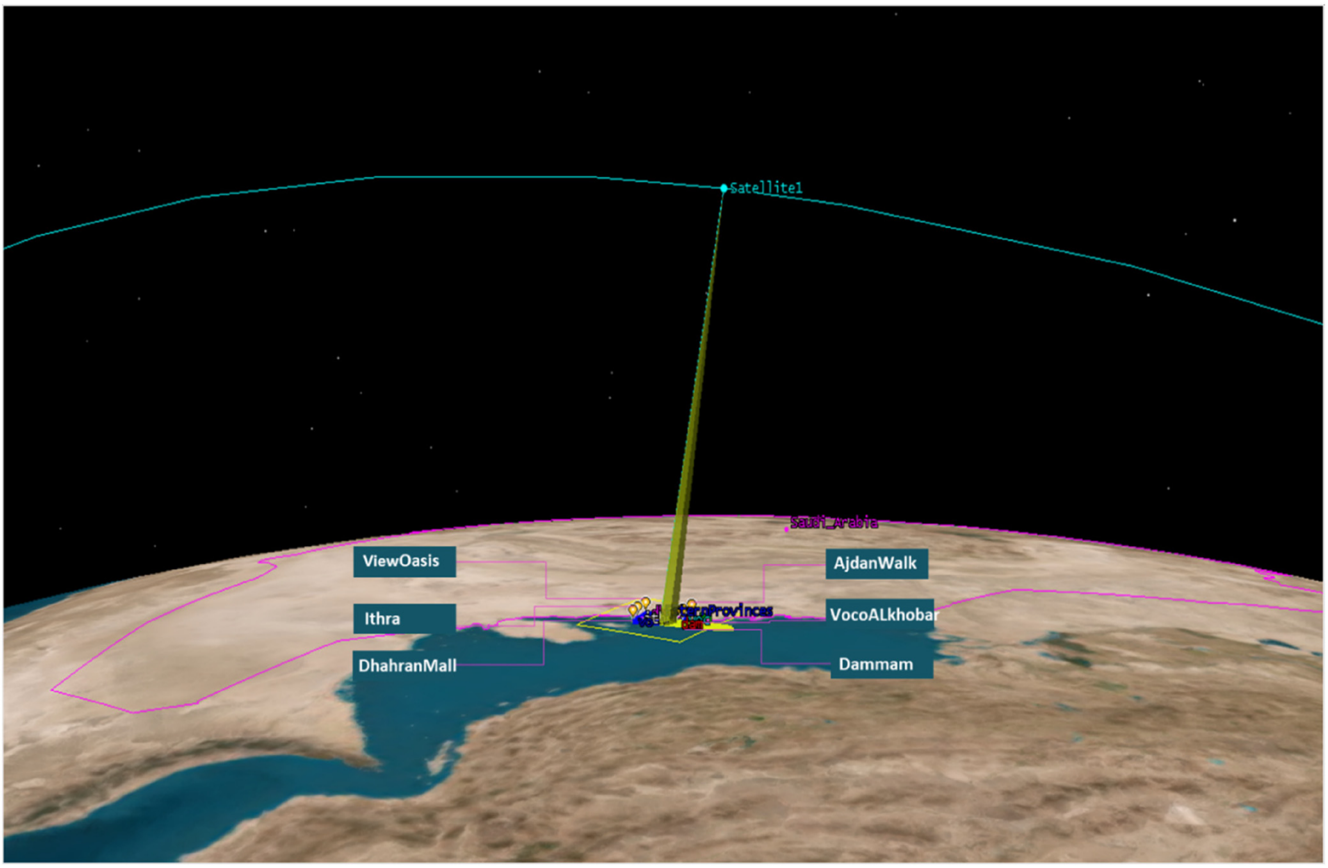

Figure 2. 3D visualization of the satellite's orbital pass over the Eastern Province showing the sensor line-of-sight and the six ground targets

4.3. Decision Variables. The decision variables include the following: (1) slew angles (pitch, yaw, roll), (2) slew rate profiles, (3) segment durations, (4) imaging window placement, and (5) FMC adjustment magnitude.

4.4. Outputs. The desired outputs are the following: (1) achieved effective swath, (2) number of strips imaged per pass, (3) effective revisit time, (4) total imaging duration, and (5) attitude maneuver feasibility.

4.5. Expanded Assumptions. The mission implements the following expanded assumptions:

1. *Sufficient Power Margin*: The power subsystem provides enough margin for aggressive ADCS maneuvers during one pass.
2. *FMC Availability*: The payload electronics allow FMC techniques to increase exposure time and prevent motion blur.
3. *ADCS Capability*: Satellite reaction wheels support multi-degree-per-second slewing at 5–6°/s with rapid stabilization.
4. *ROI Observability*: All strips of interest fall within observable latitude limits.
5. *Environmental Consistency*: The illumination conditions remain appropriate for VNIR imaging at 525 km.
6. *Operational Temperature Stability*: Slewing does not introduce thermal instabilities affecting optics.
7. *Perfect Timing Execution*: The onboard computer executes time-stamped commands with negligible delay.

4.6. Agile Attitude Scheduling. Agile attitude scheduling was implemented to enable sequential imaging of multiple spatially distributed targets within a single orbital pass. Based on the access windows identified in the previous section, time-tagged attitude commands were generated to coordinate the sensor pointing, imaging activation, and slew transitions between targets. The mission execution timeline summarized in Table 4 is structured into distinct operational modes, including pre-imaging preparation, target-track mode, active imaging windows, and post-imaging stabilization.

Figure 3. Representative CubeSat-class push broom optical payload used to illustrate typical Earth observation imaging configurations and mission simulation assumptions, based on the HyperScape100 hyperspectral imager [16]

Table 3. *Geographic coordinates of selected ground targets*

Target Location	Latitude	Longitude
Ajdan Walk	26.4137 deg	50.0688 deg
Dammam	26.4398 deg	50.1058 deg
Dhahran Mall	26.2698 deg	50.1775 deg
Ithra Center	26.28 deg	50.2 deg
View Oasis	26.3054 deg	50.2237 deg
Voco Al Khobar	26.4248 deg	50.0855 deg

. In target-track mode, the attitude control system executes commanded slews to align the sensor line-of-sight with each target, followed by short imaging windows and inter-target transitions. The imaging windows and slew intervals were scheduled in a tightly coordinated sequence to ensure that all targets were imaged within their respective access intervals while respecting the spacecraft operational constraints. The resulting timeline demonstrates the feasibility of executing agile multitarget imaging within a single orbital pass. Similar agile imaging strategies have been demonstrated for push-broom EO satellites, where attitude maneuvers are exploited to increase imaging flexibility and multitarget acquisition within a single orbital pass [14].

5. MISSION EXECUTION PLAN

5.1. Mission Definition and Inputs. An agile imaging mission is defined as the execution of a sequence of EO tasks over six selected ground targets within a single orbital pass. The mission inputs include the predefined target locations, satellite orbital configuration, and assumed payload and attitude control system characteristics. These inputs define the initial conditions for mission planning and establish the operational constraints within which the access analysis and mission execution are performed.

In this study, the imaging sequence was constructed directly from the access windows obtained in STK rather than through an automated optimization algorithm. The ordering of targets follows the temporal availability of visibility intervals while ensuring feasible attitude transitions between consecutive imaging events.

5.2. Access Window-Based Mission Execution Plan. Access analysis was conducted using STK to determine the geometric visibility between the satellite sensor and six selected ground targets within the Eastern Province of Saudi Arabia. Table 3 lists the geographical coordinates of the selected targets used in the access analysis. Figure 4 shows the imaging sequence over the targets located in the Eastern Province of Saudi Arabia.

The analysis focused on identifying feasible access windows during a single orbital pass, accounting for orbital geometry, Earth's rotation, and sensor line-of-sight constraints. The results indicated that all six selected targets were within the observable latitude limits and were accessible during the same orbital pass. These access intervals define the temporal bounds within which imaging operations can be scheduled and form the basis for the subsequent agile attitude planning.

The extracted access windows provide the required timing information for sequencing imaging operations while respecting operational constraints, including the attitude maneuvering capability and sensor exposure requirements.

5.3. Mission Operating Modes and Execution Timeline.

5.3.1. Mission operating modes . In the initial phase, the satellite prepares both its payload and attitude control systems prior to the first imaging event. This phase involves: (*i*) powering and initializing the imaging payload through the onboard computer (OBC); (*ii*) synchronizing internal timing with the mission schedule; (*iii*) stabilizing the satellite in nadir-hold or inertial-hold mode; and (*iv*) verifying that power and thermal conditions support agile operations. This mode ends when the satellite is ready to initiate the first attitude maneuver toward the initial target, as shown in Figure 5.

5.3.2. Target-track mode. In this phase, the satellite's ADCS begins executing preplanned slews to aim for the payload's line-of-sight at the upcoming ground targets. During this period, the satellite may (1) be actively slewing between targets as demonstrated in the Figure 6 or (2) holding a precise inertial attitude until the optimal imaging instant. All maneuvers were precomputed based on the STK access analysis and executed according to the exact time tags.

5.3.3. Imaging sequence mode. This mode represents the period of active data acquisition. During each imaging window the imaging sequence is as follows:

1. The payload captures imagery in its operational mode.
2. The OBC enforces the start and stop times.
3. Image data are buffered into onboard storage.
4. The ADCS maintains stable pointing to avoid motion blur.

The imaging sequence consists of multiple consecutive windows targeting six selected ground locations in the Eastern Province, executed in the order defined by the mission plan.

5.3.4. Nadir-hold mode. After the final imaging window, the satellite transitioned back to a nadir-pointing attitude. During this phase the sequence of operations is as follows:

1. The payload is powered down or placed into standby.
2. The ADCS stabilizes the satellite for routine Earth-pointing operations.
3. The OBC finalizes data logging and prepares the collected imagery for future downlink.

This mode concludes the single-pass agile imaging mission.

5.4. Imaging Timeline. The total imaging duration is 6 s, yielding a total mission execution time of 16 s, as shown in Table 4.

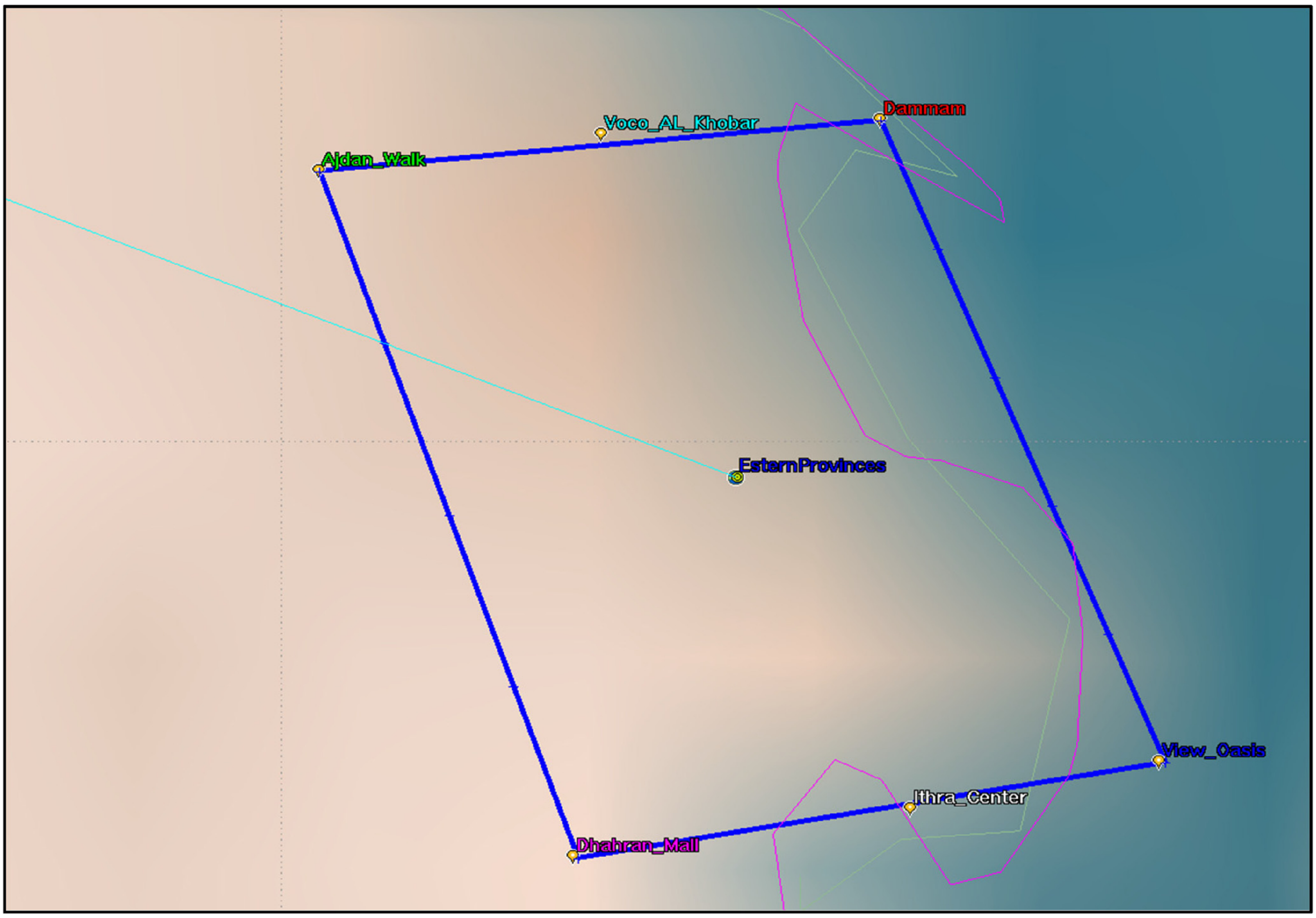

Figure 4. Agile imaging sequence over the Eastern Province of Saudi Arabia showing the satellite ground track and the spatial distribution of the six selected targets imaged sequentially within a single orbital pass

Table 4. *Imaging timeline for multi-target mission execution*

Targets	Pre-imaging preparation	Slew transition
Place/Dammam	4 Dec 2025 09:40:27.472	4 Dec 2025 09:40:27.472
	4 Dec 2025 09:40:27.472	4 Dec 2025 09:40:29.472
Place/View Oasis	4 Dec 2025 09:40:29.472	4 Dec 2025 09:40:30.472
	4 Dec 2025 09:40:30.472	4 Dec 2025 09:40:32.472
Place/Ithra Center	4 Dec 2025 09:40:32.472	4 Dec 2025 09:40:33.472
	4 Dec 2025 09:40:33.472	4 Dec 2025 09:40:35.472
Place/Voco	4 Dec 2025 09:40:35.472	4 Dec 2025 09:40:36.472
	4 Dec 2025 09:40:36.472	4 Dec 2025 09:40:38.472
Place/Ajdan Walk	4 Dec 2025 09:40:38.472	4 Dec 2025 09:40:39.472
	4 Dec 2025 09:40:39.472	4 Dec 2025 09:40:41.472
Place/Dhahran Mall	4 Dec 2025 09:40:41.472	4 Dec 2025 09:40:43.472
	4 Dec 2025 09:40:43.472	4 Dec 2025 09:40:45.472

5.5. Slew Segments.

The maneuver parameters listed in Table 5 provide quantitative validation of the ADCS feasibility for the proposed agile imaging mission. The largest retargeting maneuver requires a yaw change of approximately 15°. The maximum average yaw rate observed during the simulation was approximately 7.5°/s, while the peak slew rate was approximately 7.9°/s. These values remain within the typical operational capabilities of the commercial CubeSat ADCS, which commonly supports multi-degree-per-second slewing. Furthermore, the roll rates remain below 3°/s, and the maneuver durations are approximately 2 s, indicating that the required control authority and slew performance can be achieved using existing commercial-off-the-shelf (COTS) ADCS solutions.

Typical commercial CubeSat ADCS systems support slew rates in the range of 8–10°/s with pointing accuracies in the order of tens of arcseconds [16], indicating that the maneuver rates observed for the proposed agile imaging sequence remain well within the achievable operational limits for CubeSat class ADCS systems.

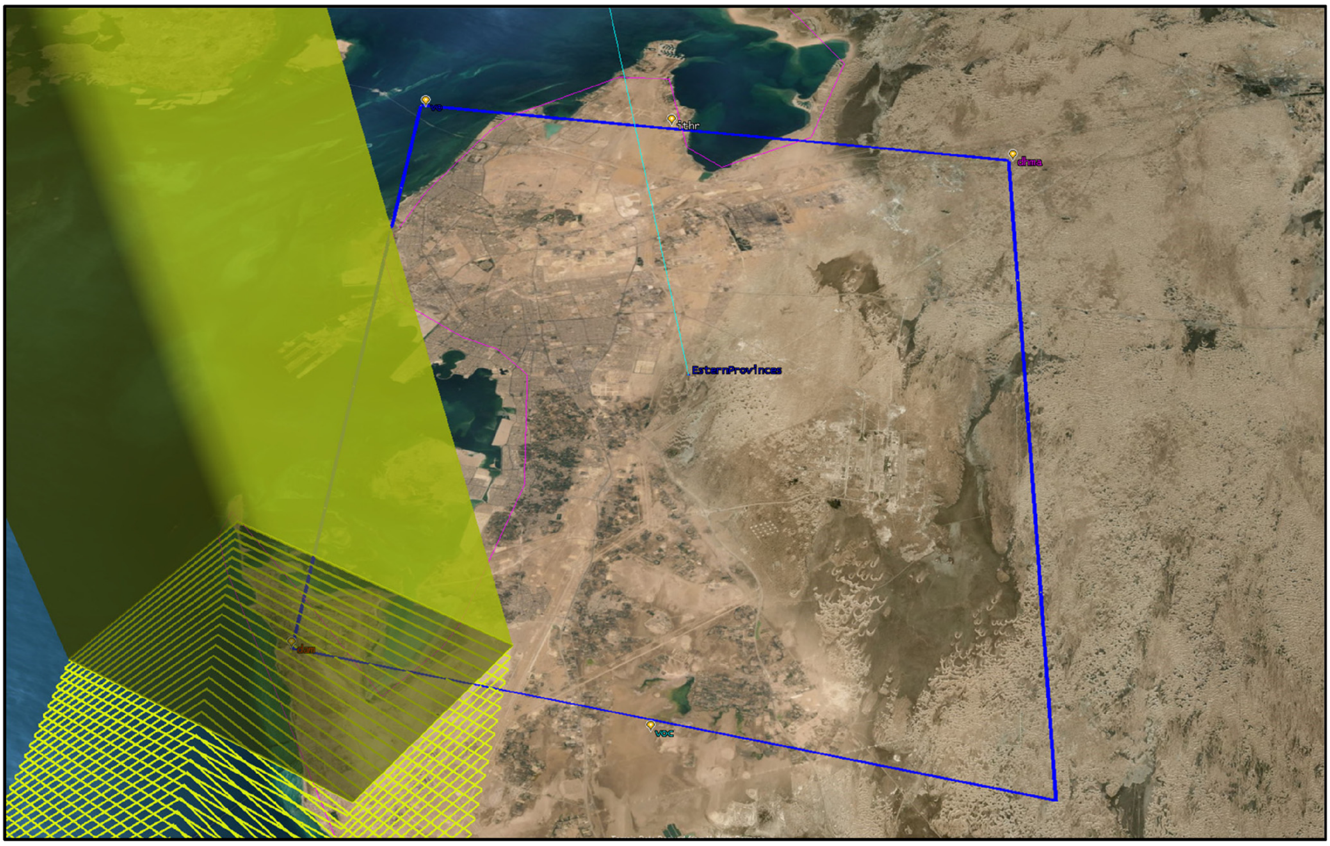

Figure 5. Satellite pointing toward the first target point to start mission execution

Table 5. *Attitude maneuver parameters for inter-target slew segments*

Segment	Duration(s)	ΔYaw (°)	ΔPitch (°)	ΔRoll (°)	AvgYawRate (°/s)	Avg Roll Rate (°/s)	Slew Rate ω (°/s)
Place/vo→Place/dammam	2	10	0.3	3.3	5.0	1.7	5.4
Place/dam→Place/voco	2	8	0.3	2.7	4.0	1.3	4.2
Place/voc→Place/ithra	2	12	0.7	4.0	6.0	2.0	6.3
Place/ithr→Place/dhmall	2	10	0.4	3.3	5.0	1.7	5.4
Place/dhma→Place/ajdan	2	15	0.4	5.0	7.5	2.5	7.9

5.6. ADCS Slew-Rate Capability Requirement.

The required average slew rate, ω_{req},is given by:

$$\omega_{req} = \frac{\Delta\theta}{(t_{gap} - t_{settle})} \tag{2}$$

where $\Delta\theta$ is the required angular displacement between consecutive targets, t_{gap} is the available time interval between imaging events, and t_{settle} is the required attitude stabilization time after each maneuver.

The acceleration-limited minimum slew time, t_{min}, is calculated as:

$$t_{min} \approx 2\sqrt{\frac{\Delta\theta}{\alpha_{max}}} \tag{3}$$

where α_{max} is the maximum angular acceleration provided by the spacecraft attitude control system.

The feasibility condition is $t_{min} \leq t_{gap} - t_{settle}$. The feasibility can be evaluated using the mission-specific parameters.

5.7. ADCS Capability Requirements.

The agile imaging mission requires an ADCS capable of providing the following:

(1) Sufficiently high maximum body rates.
(2) Angular acceleration adequate for the largest planned retargeting maneuver.
(3) Fine pointing stability during imaging.
(4) Absolute pointing accuracy within mission tolerance.
(5) Settling times of 1–1.5 s between slews.

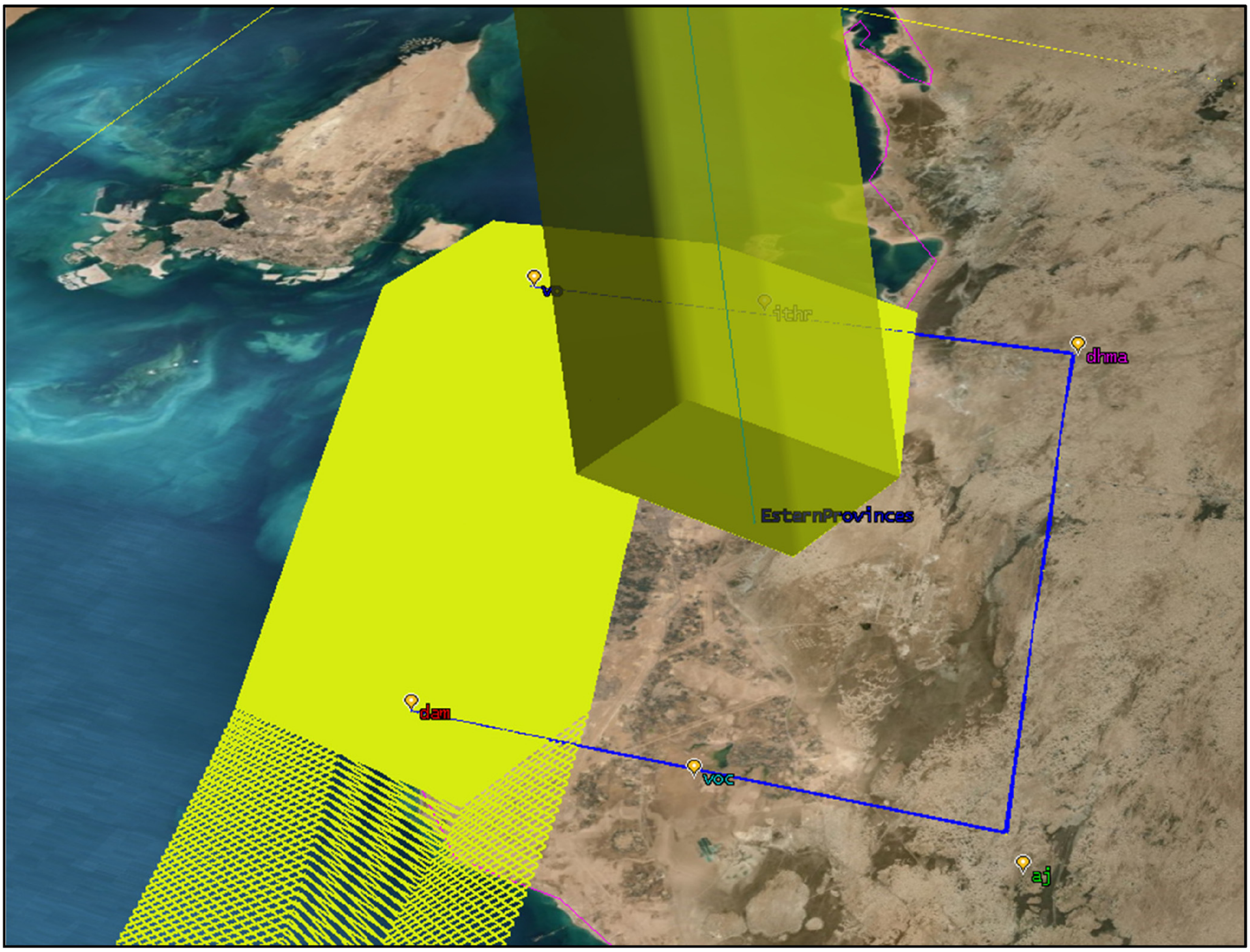

Figure 6. Satellite payload heading towards target 4 from 3 during the second strip imaging

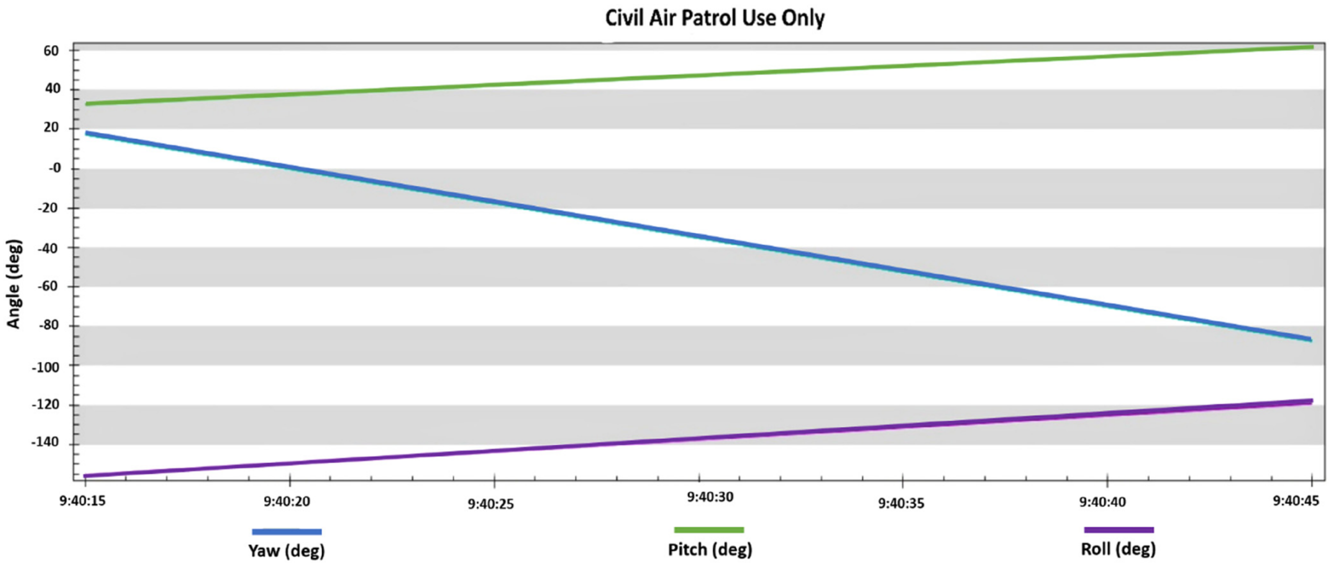

Figure 7. Satellite yaw, pitch, and roll angles versus time during the agile imaging maneuver sequence

(6) Smooth jerk-limited S-curve profiles to preserve image quality.
(7) Maximum yaw maneuver = 15°
(8) Required average slew rates = 4–8°/s
(9) Average roll rates = 1–3°/s

These requirements fall within the operational range of current commercial 6U ADCS systems.

5.8. COTS ADCS Feasibility.

Modern commercial ADCS solutions for 6U satellites, such as the cube space ADCS Gen-2 and GomSpace ADCS modules, support multi-degree-per-second slewing and provide sufficient pointing accuracy for agile imaging. They incorporate reaction wheels, advanced control loops, and optional star trackers, which make them suitable for the maneuvering profile required by the mission.

A quantitative analysis of the maneuver parameters confirmed that the proposed agile imaging sequence remained within the operational capabilities of typical commercial CubeSat ADCS systems. The maximum observed slew rate of approximately 7.9°/s and average rates in the range of 4–8°/s are consistent with the performance specifications of widely available 6U-class ADCS solutions. Additionally, maneuver durations of approximately 2 s and moderate roll rates below 3°/s indicate that the required control authority and stabilization performance can be achieved using existing COTS hardware. This provides strong evidence that the proposed mission concept is theoretically and practically viable.

6. RESULTS AND DISCUSSION

An agile imaging scenario was executed in STK for a single orbital pass over the Eastern Province of Saudi Arabia. Six distinct ground targets were incorporated into the mission timeline. Access analysis demonstrated the visibility windows for each target, which were subsequently used to construct a multi-segment imaging sequence.

To provide a baseline comparison, a nadir-only imaging scenario was simulated using the same orbital configuration and target set, with the satellite maintaining a fixed nadir-pointing attitude and no agile slewing maneuvers.

To further quantify the performance improvement, a comparative analysis of the nadir-only and agile imaging modes was conducted. Under the nadir-pointing operation, only one target can be effectively imaged within a single orbital pass owing to the limited swath coverage and restricted access geometry. In contrast, the agile imaging strategy enabled all six targets to be acquired within the same pass, representing a six-fold increase in target coverage. The total imaging duration was approximately 6 s, with an overall mission execution time of 16 s, including the intertarget slews and stabilization intervals. These results highlight the substantial performance enhancement achieved through agile attitude control without the need to increase the system complexity or payload capability.

The extracted imaging windows from STK confirmed that each target was successfully observed within its corresponding access interval. The satellite completed all six imaging tasks in a single pass with an aggregate imaging duration of 6 s distributed across six individual target imaging time windows. The slewing and attitude settling phases between imaging windows required an additional 10 s, resulting in a total operational execution time of 16 s.

A series of inter-target slews were simulated to assess the maneuvering workload imposed on the ADCS. The yaw, pitch, and roll adjustments for each re-targeting maneuver summarized in Table 5 are plotted in Figure 7. The largest retarget required a yaw change of approximately 15°and roll change of 5°, which are consistent with the geometry of the target distribution. The average yaw rate remained within 5.5°/s, which is well below the maximum allowable rate for 6U-class ADCS.

Timeline analysis demonstrated that the satellite maintained a stable pointing during all imaging windows, with attitude variations remaining within acceptable bounds for EOs. No imaging interval violated the alignment or exposure constraints.

The maximum required attitude rates observed in the simulation are within the assumed ADCS capabilities. Specifically, the highest average yaw rate required was approximately

5.5°/s, which is consistent with the multi-degree-per-second slewing performance reported for commercial 6U-class ADCS. No maneuver exceeded the assumed control authority, confirming the internal consistency between the attitude assumptions and simulated maneuver profile.

Although the primary focus of this study was on mission feasibility and attitude maneuvering, detailed optical image quality modeling, including modulation transfer function degradation and motion smear effects, is beyond the scope of this study. Nevertheless, the maneuvering characteristics observed in the agile imaging sequence suggest that the image quality should remain within acceptable operational bounds. The simulated attitude transitions maintained moderate slew rates, with maximum values below approximately 8°/s, and maneuver durations of approximately 2 s between the targets, allowing sufficient stabilization before each imaging event.

In addition, the off-nadir pointing angles remained moderate relative to the satellite ground track, thus limiting geometric distortion and maintaining adequate ground-sampling consistency. These factors indicate that the image degradation remains limited for the push broom imaging configuration considered in this study.

7. CONCLUSIONS AND FUTURE WORK

This study demonstrated the feasibility and effectiveness of a software-driven agile imaging mission for a 6U EO satellite using STK. These findings reinforce the growing importance of software-driven mission planning for next-generation small satellite systems. By leveraging agile attitude control and time-tagged command execution, it is possible to significantly enhance imaging coverage and revisit performance without increasing the hardware complexity. This reflects a paradigm shift in EO mission design, where software-driven operational strategies complement physical system capabilities to achieve performance levels that are traditionally associated with larger or multi-satellite systems.

The simulated maneuver profiles remained within the capability envelope of representative 6U-class ADCS, confirming both operational feasibility and engineering consistency. These results highlight the practical value of optimizing attitude agility and mission timing to enhance coverage and responsiveness in small-satellite EO missions. While this study demonstrates the feasibility of agile multitarget imaging using STK-based mission planning, several aspects warrant further investigation. These include explicit modeling of ADCS actuator dynamics and jitter effects, detailed analysis of image blur and exposure-time during slewing, automated target scheduling under competing access constraints, and the incorporation of spacecraft power availability and duty cycle limitations to further enhance operational realism.

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