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An investigation of automation strategies to optimize ITASAT2 mission operations

Renan Guilherme Soares Menezes, Lidia Hissae Shibuya Sato, Edson Wander do Rego Pereira, Victoria de Souza Rodrigues, Luis Felipe Camponogara, Victor Oliveira Costa, Ana Carolina di Iorio Jeronymo, Luís Eduardo Vergueiro Loures da Costa
Instituto Tecnológico de Aeronáutica
Praça Marechal Eduardo Gomes, 50 - Vila das Acácias, São José dos Campos - SP, 12228-900; +55 (12) 3305 8565
renang@ita.br

ABSTRACT

The ITA Space Center (CEI) is dedicated to advancing space systems and cultivating expertise in the sector. In pursuit of these objectives, CEI has initiated CubeSat development projects, commencing with the ITASAT mission launched in December 2018 and followed by the successful deployment of the SPORT satellite project in 2022. ITASAT's primary purpose was to be a hands-on project, from design to operation. SPORT is designed to study space weather, specifically focusing on the dynamics of plasma bubble formation in the ionosphere near-equatorial regions. Acknowledging the inherent challenges posed by power budget limitations, it became apparent that continuous scientific data collection was unattainable. As a result, a strategic decision was made to implement a power management strategy, composed of power monitoring and a science scheduler incorporated into the satellite's infrastructure. Currently, CEI is actively developing the ITASAT2 mission—a constellation comprising three 12U satellites. The mission aims to extend the scientific investigation initiated by the SPORT mission, enhancing temporal resolution and expanding objectives to include ground-based RF source geolocation. Despite persistent power limitations, the power management strategy employed in the SPORT mission with the integration of power monitoring and science scheduler is crucial for optimal resource management for the ITASAT2 mission. The ITASAT2 mission has increased in complexity due to the introduction of in-flight formation operations and geolocation technology demonstrations. Addressing these requirements, and drawing on the lessons learned from the SPORT mission, a proactive approach is being pursued to explore the development of autonomous operations. This paper proposes an investigation of possible strategies for automating ITASAT2 mission operations to maximize satellite resources for collecting and delivering scientific data.

INTRODUCTION

The ITA Space Center (CEI), located in São José dos Campos, Brazil, is dedicated to the formation of human resources and in the research and development of space technology, including CubeSat missions [1]. In the last six years, CEI has launched two 6U CubeSat missions and is currently developing two more 12U CubeSats missions, leveraging the knowledge gained thus far. In 2018, the ITASAT CubeSat was launched and successfully operated in low Earth orbit (LEO). This mission was crucial for the consolidation of the ITA Space Center, demonstrating that students can be effectively involved in the real-world activities of designing, assembling, integrating, and testing a space system. Following ITASAT, the SPORT (Scintillation Prediction Observations Research Task) CubeSat was launched in 2022, marking a new milestone for CEI. It was the first CubeSat developed in Brazil that hosted a suite of science instruments provided by the United States [2]. Stakeholders in the project included the FAPESP, the Brazilian Space Agency, NASA, the US Department of Defense, and US Universities [3].

These first two missions played a crucial role in equipping and training individuals in satellite operations. For the first mission, ITASAT, the Aeronautics Institute of Technology (ITA - Instituto Tecnológico de Aeronáutica) was responsible for operating the satellite in partnership with two regional centers from the National Institute for Space Research (INPE - Instituto Nacional de Pesquisas Espaciais): the regional center of Natal and the regional center of Santa Maria [4]. The second mission, SPORT, was operated by INPE in partnership with ITA [5]. Collaborating with the CEI team, daily contact with operations revealed the challenges of sending telecommands and receiving telemetry during the brief periods of satellite passes. Consequently, the team involved in operations discerned that part of their communication with the satellite could be automated, thereby reducing the number of telecommands and the time between each telecommand or telemetry.

From 2020 to the present, CEI has been developing a new mission with different capabilities: the ITASAT2 mission. This mission, composed of three 12U CubeSats in a formation flight, aims to study space weather and develop and demonstrate geolocation capabilities [6]. Given the complexity of the tasks these CubeSats will perform, the initial concept of operations is being carefully studied. Drawing from lessons learned from ITASAT and SPORT operations, CEI engineers have designed a preliminary scheme for ITASAT2 operations, including automated tasks such as science scheduling and the downlink of telemetry and beacons. Therefore, the main objective of this paper is to present the primary discussions on this topic, the diagrams representing the baseline for operations, and the main concerns related to the ground segment and observatories. Future work will also be discussed in the conclusions section.

ITASAT AND SPORT MISSION OPERATION

This chapter is dedicated to a comprehensive analysis of the operations associated with the ITASAT and SPORT missions. These missions served as the groundwork for the operational framework of the ITASAT2 mission. The ITASAT project, which received support from The Brazilian Space Agency (AEB - Agência Espacial Brasileira), was primarily aimed at the capacity building of human resources for the space sector. The project team was entrusted with supervising all phases of the mission, spanning from its conception to its operational stage. The ITASAT mission, after some changes since its initial conception, which was a microsatellite, was configured as a 6U CubeSat, planned to operate four distinct experiments. These included the national development of a GPS receiver, a data collection transponder compatible with the existing Brazilian data collection system, a commercial camera functioning within the visible spectrum, and a communication experiment involving radio amateurs.

ITASAT Mission Operation

The Concept of Operations (ConOps) for the ITASAT mission is relatively straightforward, primarily due to its manual development by the satellite development team. Figure 1 provides an overview of the operational framework of the ITASAT mission.

Figure 1 shows the communication relationship between ITASAT in orbit, with the Planner, the Tracker, and Mission Control represented by CEI personnel. The Amateur Radio community is depicted by multiple boxes, indicating numerous users and the three ground stations (GS) used to operate the satellite: INPE-ITA, INPE-CRS, and INPE-CRN.

The Tracker is responsible for using the Two-Line Element (TLE) file, ground station locations, and timing to estimate satellite passes over ground stations. This information is summarized in tracking information.

The Planner uses the tracking information to plan all activities, which are then sent to the ground station. The plan includes a list of telecommands, passage times frequencies, and other information.

Ground Stations and Communication for ITASAT

The mission involves three Brazilian ground stations capable of sending telecommands and receiving telemetry data: INPE/ITA in São José dos Campos, INPE-CRS in Santa Maria, and INPE-CRN in Natal. For the operation, at least 2 operators at each ground station were required. Ground round stations used AFSK modulation on the uplink and BPSK modulation on the downlink. a data rate of 1200 bps was used on both uplink and downlink.

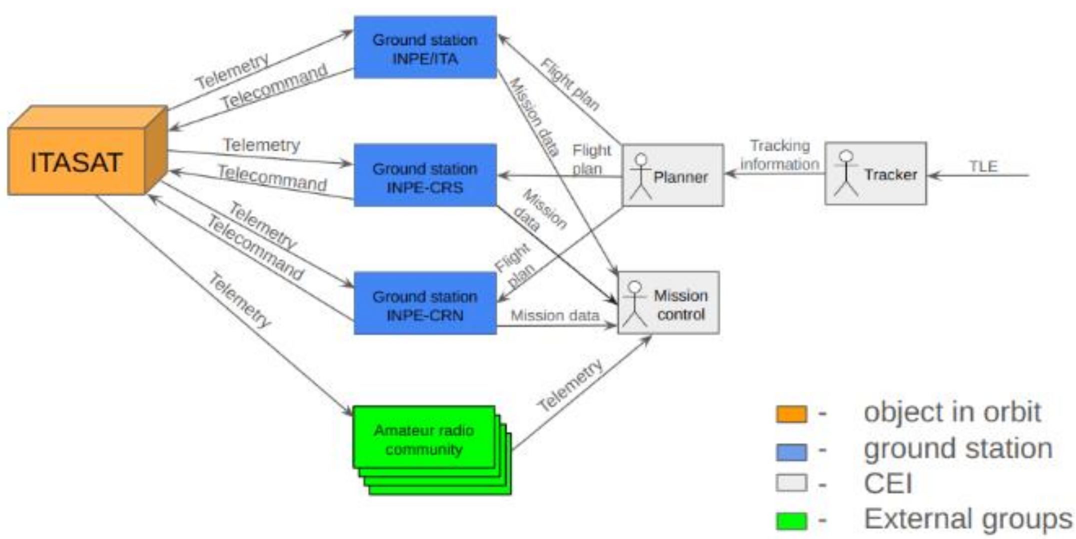

Figure 1 - Operational framework of the ITASAT mission.

Additionally, the amateur radio community participated in the operation of the satellite by receiving telemetries and forwarding them to the mission center.

Operational Sequence and Challenges for ITASAT

The sequence of operations for the ITASAT mission is outlined in Figure 2. The flight plan is prepared before the satellite passes over a ground station. Operations begin upon receipt of the satellite beacon and telemetry containing basic information of ITASAT. Mission control then dispatches commands to the satellite and receives corresponding telemetry data.

This operation sequence has significant limitations due to its reliance on human intervention for planning and operations, and its lack of process automation. Satellite operation depends on telecommands for instrument activation and deactivation. However, its simplicity facilitates implementation and operation.

Overview of SPORT Mission and Operations

In the SPORT mission, Brazil partnered with the United States for a joint mission development. Brazil was responsible for the development of the spacecraft, assembly and integration tests, and operations, while the United States was responsible for the development of the payloads and the launch services. The scientific mission, aimed at investigating the formation of plasma bubbles and scintillation within the ionosphere, was a collaborative effort between Brazil and the United States. The treatment of the data and the scientific

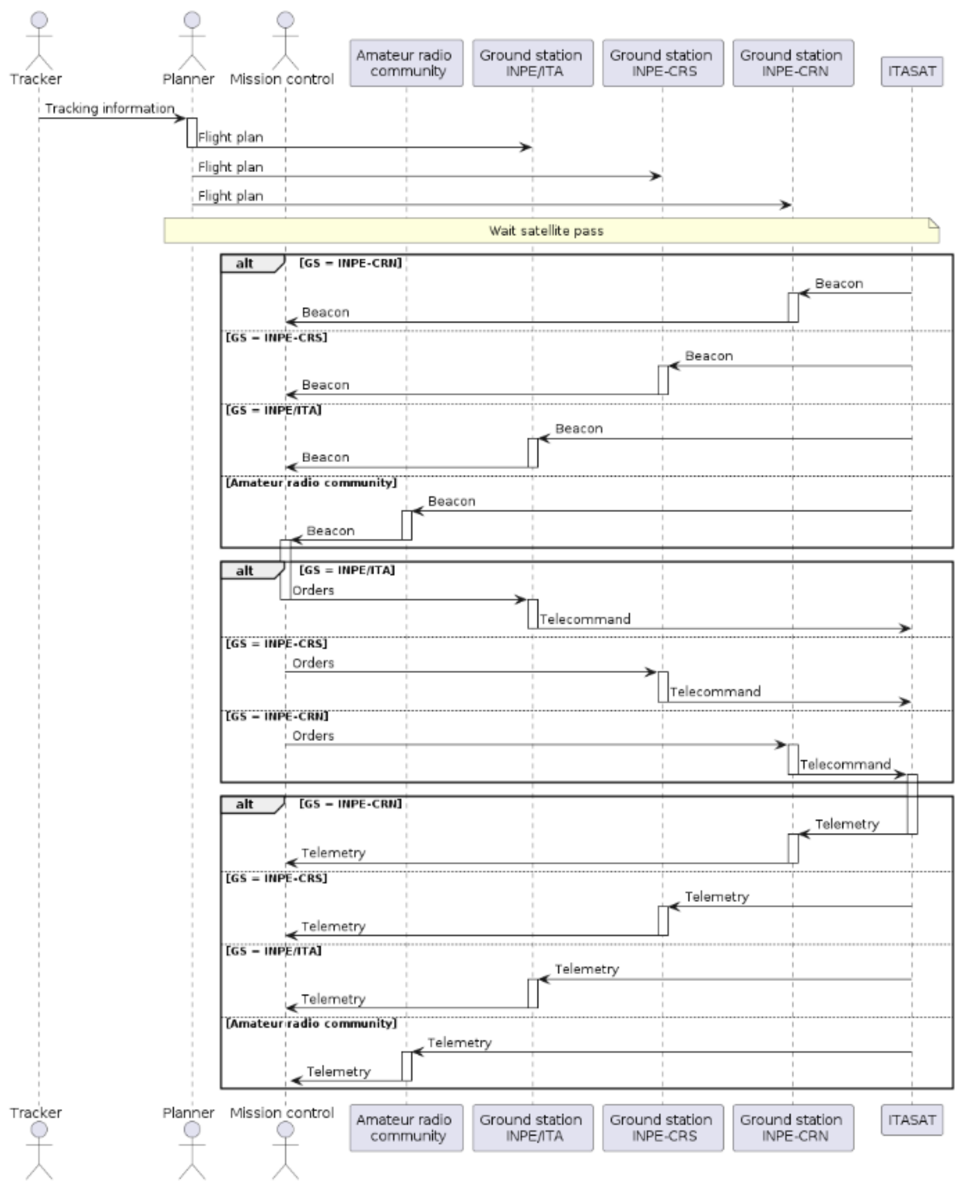

Figure 2 - Sequence of operations for the ITASAT mission.

investigation are expected to be carried out jointly by both countries.

Key Brazilian institutions included ITA, AEB, INPE, and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). North American partners included The University of Alabama in Huntsville (UAH), Utah State University (USU), Aerospace Corporation, University of Texas at Dallas (UTD), NASA Marshall and NASA Goddard. The project also had support from the US SouthCom.

Compared to ITASAT, the ConOps of SPORT is more complex, involving multiple institutions and entities such as CCS-INPE, GS-INPE, CEI, payload principal investigators (PI), and the broader scientific community. Figure 3 illustrates SPORT operations.

As depicted in Figure 3, SPORT represents the satellite in orbit. It is operated by two ground stations: INPE-Natal, operating in VHF/UHF, and INPE-Cuiabá, operating in VHF/UHF and X-Band. The Satellite Control Software (SATCS) was employed for satellite operations. The team responsible for satellite operations was composed of various groups, including those dedicated to flight dynamics, satellite engineering (ENSAT), satellite controllers (CONSAT), spacecraft subsystem specialists, and the operation leader (LIDSAT). While the CONSAT and ENSAT access a controller instance of SATCS, the specialists and LIDSAT access a visualization instance of SATCS.

Flight dynamics, similar to the Tracker in ITASAT, summarizes satellite pass details in tracking information, which is sent to ENSAT and helps LIDSAT to prepare the operation plan and program the telecommand list in SATCS.

The ground stations in Natal and Cuiabá use VHF for telecommand uplink and UHF for spacecraft telemetry's downlink. Cuiabá's X-band ground station downloads mission data. The CONSAT operates SATCS, dispatching telecommand lists prepared by ENSAT, which executes the LIDSAT's operation plans, and providing feedback on the status of the communication link.

After Cuiabá's X-band ground station receives mission data, EMBRACE is responsible for processing it to obtain level 0 data, which is then sent to the instruments' PI for further processing. Later, the PI of each instrument sends level 1 and level 2 data back to EMBRACE so it can make the data available to the broader scientific community.

Autonomous operation of SPORT mission

The SPORT satellite included a self-managing system called the Science Scheduler responsible for deciding when to collect and store scientific data, considering mission requirements and power budget restrictions. The Science Scheduler activated the satellite's science mode when it was in a region of interest, according to the requirements of scientific instruments. Another system, the Power Monitor, regularly evaluated battery voltage and current levels, enabling autonomous control to lower power consumption modes. The science scheduler factored in the scientific significance of specific moments, concentrating data collection efforts within latitudes ranging from -30 to +30 degrees during the ascending or descending node, particularly between the local times of 5 PM to 2 AM. The approach of these two integrated solutions minimized power usage during periods deemed less critical for scientific observations.

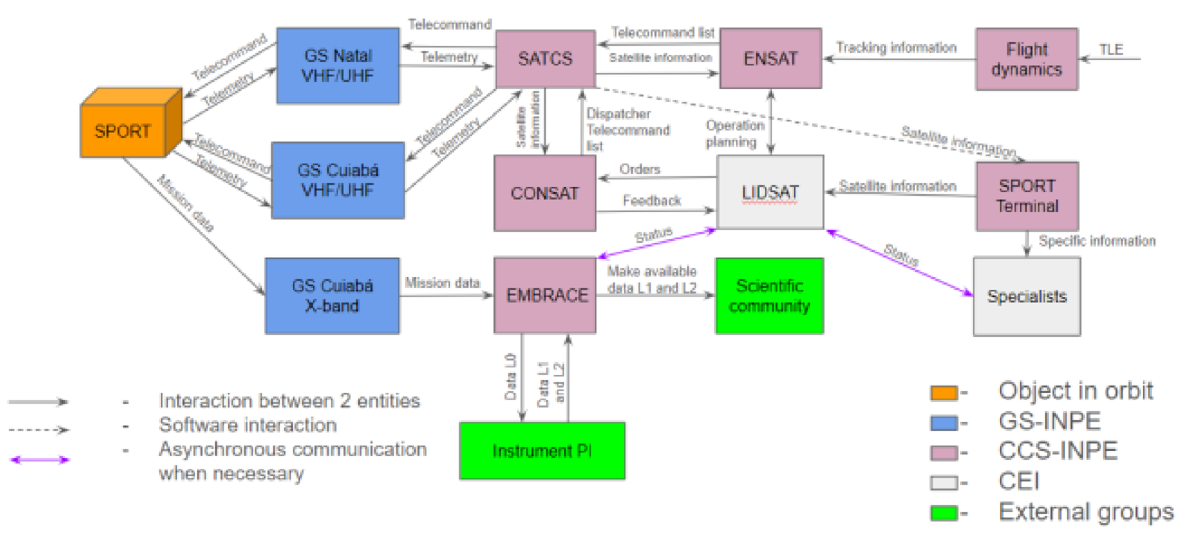

Figure 3 – SPORT Operation diagram.

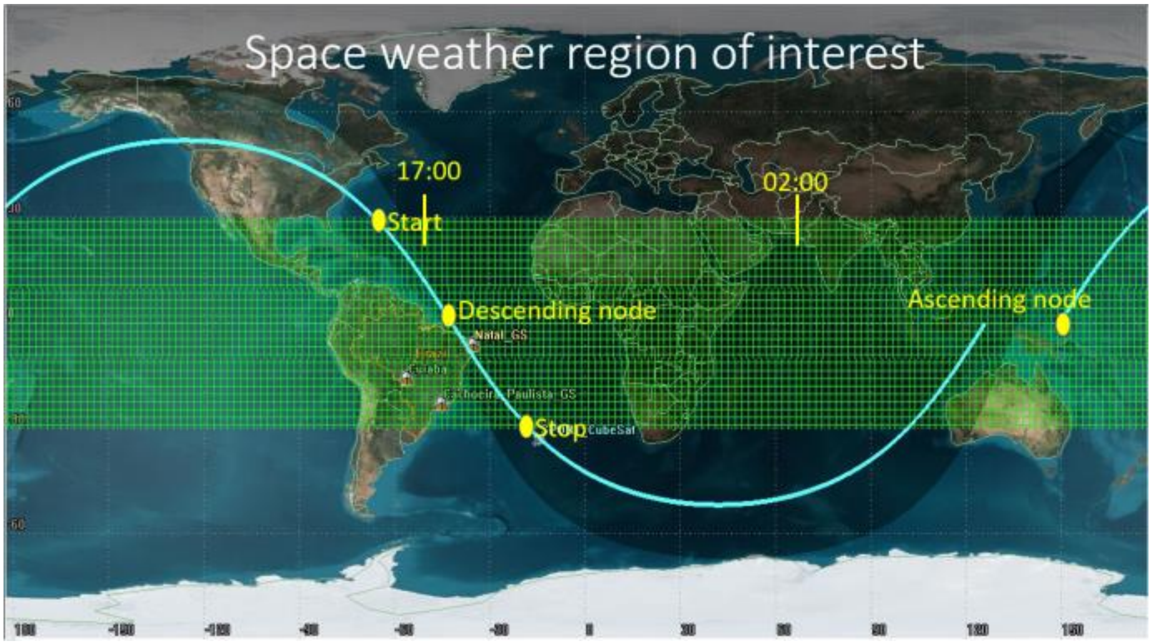

Figure 4 - Space Weather Region of Interest of SPORT mission.

Figure 4 above depicts an example of a satellite passing over a region of interest, where the Science Scheduler automatically initiated the data collection. The implementation of the Science Scheduler uses a finite state machine which propagates the satellite's orbit to decide when and how to act over the state of the spacecraft.

However, there are times when the satellite's orbit drift prevents observations of the usual region of interest in space weather as shown in Figure 5. This can happen because the ascending or descending nodes are not in the Local Time (LT) of interest. To maximize scientific output during these periods, SPORT could adjust the science scheduler's parameters. By changing the region of interest, SPORT collected data from other potentially valuable areas, ensuring continuous scientific return.

Lessons learned from the SPORT operation

The SPORT mission's operational complexity was significantly greater than that of the ITASAT mission. Unlike ITASAT, SPORT had to operate continuously, including on weekends. This involved numerous groups from different institutions, leading to intricate human relations, especially when unforeseen issues arose. Additionally, the organizational infrastructure used was

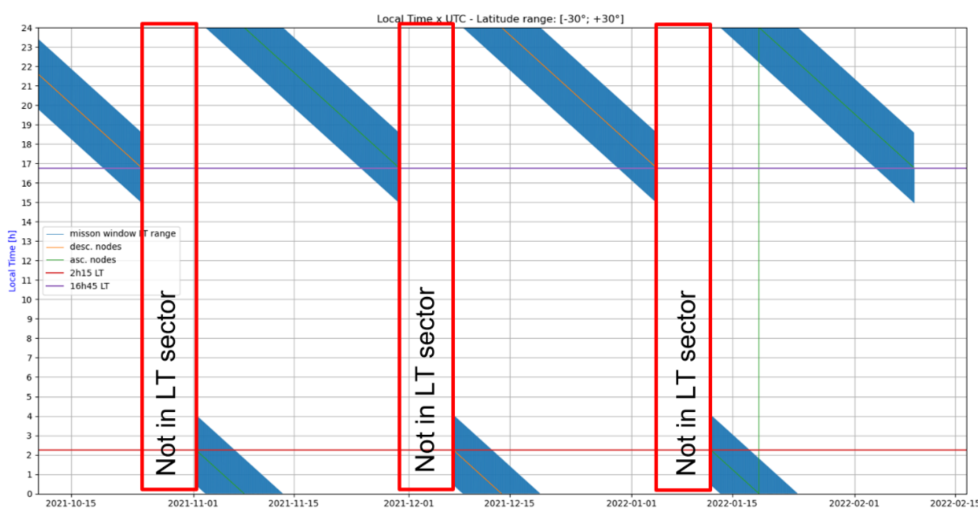

Figure 5. Regions which demand adjusting the Science Scheduler parameters of the SPORT mission.

typically reserved for larger missions, contributing to a higher cost of operations due to the large number of people involved.

The SPORT mission encountered issues with the X-band link because the attitude control system did not perform as expected. Consequently, the spacecraft's final attitude was not as designed, resulting in a non-nominal X-band antenna pointing towards the ground station reference. As a consequence, the access time to the satellite in this band was shorter than expected, limiting data transfer in a single pass. Additionally, the organizational and operational routines of the institutes, which do not include shifts from midnight to 6 AM local time (Brazil), which is comprehensive to reduce operational costs, highlighted the need to automate certain processes to maximize the number of successful passes for satellite operations.

THE UNION OF AUTOMATION AND MACHINE LEARNING FOR SPACE MISSIONS

The spacecraft mission operations and management involve large teams working together. Coordinating and supporting them, along with the communication network, is expensive. For this reason, space mission managers are constantly looking to streamline operations and reduce costs or risks. One approach is to employ more functions onboard the spacecraft, reducing the need for a large operations team. Here, automated operation could be defined as the ability of a spacecraft to perform functions without human intervention [7].

For certain missions, such as interplanetary or very expensive ones, some degree of autonomy is essential. Interplanetary missions, for example, must operate with long communication delays due to the extreme distances involved. The onboard software needs to deal with any contingency without waiting for instructions from Earth. Human error is another strong argument for improved spacecraft autonomous operation. Errors can be a source of mission failure, as shown by the Russian Phobos mission and the NASA Mars Climate Orbiter, where erroneous commands from operators led to mission termination [7].

Machine learning offers a powerful solutions, enhancing spacecraft autonomy and decision-making, leading to significant time and cost savings. This efficiency enables more achievements within the limited lifespan of spacecraft, which is often restricted by harsh environmental factors, component degradation, and finite resources. These constraints contribute to the high cost of mission maintenance, sometimes leading to decommissioning of even functional hardware due to budget limitations [8].

Machine learning is transforming satellite operations [9], but space missions bring their challenges. Squeezing powerful hardware onto a spacecraft is tricky due to size, weight, and power limitations. Ground systems, however, can analyze massive datasets from satellites without the limitations of onboard processing. This lets them use more complex algorithms for deeper insights and better predictions. They're also more flexible and scalable, allowing for powerful hardware and adaptable algorithms [10].

However, communication constraints result in reduced real-time data reception by ground systems. Although, this limitation is acceptable for certain applications. For instance, anomaly detection for space systems, powered by machine learning, can identify potential equipment failures through telemetry data analysis. In this context, ground systems assume a pivotal role by employing more robust algorithms to enhance accuracy [10].

The use of automation and machine learning in satellite operations can significantly reduce operational costs for both the space segment and the ground segment. For example, the EO-1 spacecraft, by employing machine learning in the Autonomous Sciencecraft Experiment, was able to cut operational costs by $1 million per year and increase its science return by 50%, demonstrating the transformative impact of machine learning in space [11].

To implement automation and machine learning in CubeSat projects, some aspects need to be considered, such as:

Resource Constraints: The limitations of space hardware, such as size, weight, and power, pose significant challenges to implementing advanced automation and machine learning algorithms onboard spacecraft. Balancing the computational requirements of these technologies with the available resources is crucial.

Communication Delays: Communication constraints between satellites and ground systems result in reduced real-time data reception. This limitation imposes a balance between onboard processing capabilities and the need for ground-based analysis, especially for applications requiring timely decision-making.

Autonomy vs. Human Intervention: The level of autonomy required for satellite operations varies depending on the mission objectives and environmental factors. Deep space missions, for example, often require a high degree of autonomy to deal with long communication delays and unforeseen contingencies, minimizing reliance on human intervention.

Risk Mitigation: Improved spacecraft autonomous operation can help mitigate the risk of human errors, which have historically led to mission failures. By reducing the need for manual intervention, automated systems can enhance mission reliability and resilience.

Cost Savings: Automation and machine learning offer significant cost-saving opportunities for satellite missions. By reducing the reliance on ground-based operations and optimizing resource utilization, these technologies can cut operational costs while increasing mission efficiency and scientific output.

Science Return: The integration of machine learning in satellite operations, as demonstrated by the Autonomous Sciencecraft Experiment on EO-1 spacecraft, has the potential to enhance the scientific return of missions. By autonomously analyzing data and making decisions, satellites can adapt their operations to maximize scientific discoveries within the constraints of their mission parameters.

Adaptability and Scalability: Ground systems have the advantage of being more adaptable and scalable compared to onboard spacecraft systems. Leveraging ground-based analysis allows for the use of more complex algorithms and deeper insights, contributing to improved decision-making and mission outcomes.

Robustness and Accuracy: Ground systems play a pivotal role in ensuring the robustness and accuracy of machine learning algorithms used in satellite operations. By employing more robust algorithms and enhancing data analysis capabilities, ground-based systems can compensate for the limitations of onboard processing and communication constraints.

PROPOSED ARCHITECTURE FOR ITASAT2

ITASAT2 Concept of Operation

The two-year operation of the ITASAT2 mission is divided into phases, each with its respective tasks. Table 1 presents the timeline, phases, and expected tasks in the mission duration.

ITASAT2 Mission Operations

In the LEOP (Launch and Early Orbit Phase) and the commissioning phase of the mission, characterized by a period with numerous uncertainties, automation can complicate the situation due to the need to handle many exceptions to make the best decisions for the mission. However, once the LEOP phase is completed and the mission enters nominal mode, the satellite's operations become routine, allowing automation of tasks to reduce the need for human intervention. Figure 8 shows the diagram of the expected nominal operation of the ITASAT2 mission.

Table 1 – ITASAT2 mission phases

Timeline	Phases	Tasks
-	Jettison	-
T0	LEOP	- Initialization
T0 + 0 months	Commissioning	- Spacecraft Commissioning - Payload Commissioning
T0 + 3 months	No Flight Formation	- Routine operation - Geolocation demonstration - Space Weather
T0 + 4 months	Formation Flight Demonstration (String of Pearls - Transition)	- Routine operation - Geolocation demonstration - Space Weather
T0 + 6 months	Formation Flight Demonstration (String of Pearls - Station Keeping)	- Routine operation - Geolocation demonstration - Space Weather
T0 + 8 months	Formation changing Demonstration (RGT - Transition)	- Routine operation - Geolocation demonstration - Space Weather
T0 + 10 months	Formation Flight Demonstration (RGT - Station Keeping)	- Routine operation - Geolocation demonstration - Space Weather
T0 + 12 months	Maneuver to an altitude of 395 km (Transition)	- Routine operation
T0 + 12 months	Formation Flight (RGT - Station Keeping)	- Routine operation - Space Weather - Geolocation demonstration - Geolocation demonstration + Space weather
T0 + 24 months	Disposal	

Human actions will be sent to operation automation through a user interface that will receive configuration and operation as input. At this moment, it hasn't been defined exactly what these actions will entail, but there are some ideas such as downloading mission data, keeping flight formation, Collect data science, and others.

Operation Automation is the most crucial block in this operational diagram. Within its confines a symphony of autonomous processes, each meticulously orchestrated to manage distinct functionalities: telecommunication, control, EPS data, and board computer data.

ITASAT2 Operation automation strategies

The ITASAT2 mission employs a range of automation strategies to streamline operations and leverage machine learning capabilities. Here's a breakdown of the different automation levels used:

Manual: A human operator takes complete control of a task. This might involve monitoring systems, making decisions, and issuing commands directly to the spacecraft.

Semi-automatic: In this mode, there's a collaboration between the human operator and the onboard systems. The system might automate certain aspects of the task, while the human oversees the process, makes judgments, and provides inputs as needed.

Automatic: The system operates entirely on its own, without any human intervention. It can perceive its environment through sensors, make decisions based on pre-programmed algorithms, and execute actions without needing human oversight. Table 2 presents various functions of the spacecraft along with their corresponding levels of automation.

The automation levels in this table have been carefully considered for each function listed. A macro explanation of how some of these functions will be implemented for the ITASAT-2 mission will be discussed in the following sub-section.

Table 2 –Levels of automation for certain functions in spacecraft

Automation Topic	Level of automation
Software Updates	Manual
Mission Data Downloads	Automatic
Telemetry/Telecommand & Log Monitoring	Semi-automatic
Anomaly Handling	Semi-automatic
Orbit Control and Maintenance	Semi-automatic
Collision Avoidance	Manual
Calibration & Validation	Semi-automatic
Ground Station(s) Tasking	Automatic
Mission data collection and technological demonstration	Automatic

ITASAT2 Telemetry/Telecommand & Log Monitoring operation

Most GSaaS providers operate using a store-and-forward scheme where all ground-station uplink activities are previously planned and consolidated. A ground station then transmits data (telecommands and software) updates) as batches to the satellite. This approach maximizes the data throughput on the uplink and overall system performance. On the downlink, the same approach takes place. All received telemetry and mission data are stored in files and then forwarded to mission control.

For the ITASAT2 mission, a store-and-forward approach will be implemented as a system requirement. Both on the ground (mission control) as well as on the space

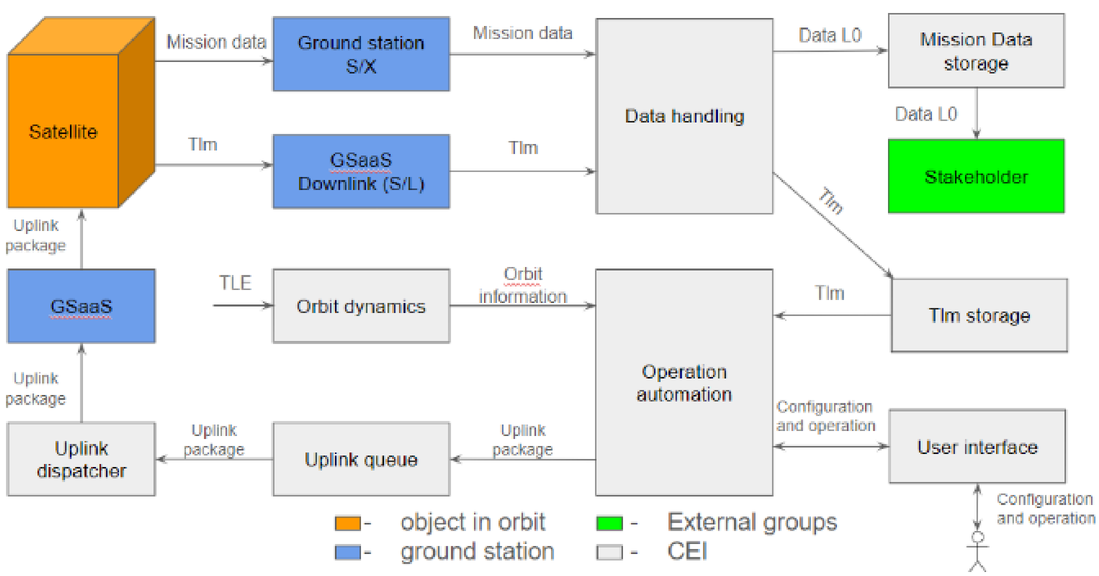

Figure 8 – ITASAT2 operational diagram.

(satellite) segments. This will be accomplished using a model where files containing scripts, telecommands, software upgrades, etc., will be prepared for a given ground station and delivered to the ground station before a satellite pass. The GSaaS provider will then upload the file to the satellite. After the file is received at the satellite, the onboard software will authenticate the file, verify the integrity of the file and will process it. The results for the processing will be included on a log file that will be inserted on the downlink queue. Upon reception by the mission control, the log file will be analyzed by the ground automation software and actions could be taken by the ground segment automation.

ITASAT2 Mission Data Downloads

The downloading of mission data will make use of the same approach as described above. The mission scheduler onboard the satellite will collect data from sensors and store the data onboard the satellite. Using the internal scheduler configured by previously received telecommands, the satellite will then activate the X-Band transmitter when it is in view of a given ground station and will transmit the mission data. The GSaaS provider will store the mission data in a file that can be fetched by the mission control system.

ITASAT2 Mission data collection and technological demonstration operation automation

ITASAT2 will utilize an autonomous system like the SPORT satellite's "Science Scheduler" for collecting scientific data. This system will focus data collection efforts on designated regions of interest (ROIs) to optimize power consumption due to limitations in onboard power generation.

Here's how ITASAT2 will improve upon SPORT's approach:

Automatic ROI Selection: Like SPORT, ITASAT2 will employ an automated system that allows for in-flight adjustments to the predefined ROIs. This enables stakeholders to adapt data collection priorities based on new scientific insights or emerging events. Even while the satellite operates autonomously, these adjustments can be made to optimize the scientific return within the designated power constraints.

Geolocation technological demonstration: ITASAT2 goes beyond SPORT by implementing a technological demonstration of geolocation. This enables the satellite to perform geolocation of ground sources, but only from designated ROIs.

By implementing these functionalities, ITASAT2 will operate more efficiently by focusing its scientific efforts on predetermined areas while minimizing power usage during less critical periods. This approach ensures optimal scientific data collection within the constraints of the satellite's power generation capabilities.

ITASAT2 Orbit Control and Maintenance Operation

The ITASAT2 will be the first satellite developed by CEI equipped with propulsion capabilities and designed to demonstrate flight formation. This ambitious undertaking necessitates careful strategies to ensure mission success. One critical aspect is the planning and execution of maneuvers, which requires a powerful combination of automation and human expertise.

The maneuver reservation system offers an efficient way to schedule and automate ITASAT2 maneuvers. However, achieving successful maneuvers relies on a crucial element: the expertise of a human operator working alongside the automation. Here's how we can leverage this collaboration for the ITASAT2 mission.

Planning for Success - Reservations with Operator Input: The first step involves defining the desired outcome of the ITASAT2 maneuver, be it orbit correction or station keeping. Then, a maneuver reservation is created in the Mission Control system. This reservation specifies the intended time window and initial maneuver parameters based on simulations.

Critically, the operator doesn't simply accept this reservation at face value. Their expertise is vital for reviewing the reservation and verifying its compatibility with the latest ITASAT2 telemetry and orbit data. Based on their findings, they might refine the reservation parameters or suggest an alternative time window to optimize the maneuver or avoid conflicts with assured space weather and geolocation tasks. If such conflicts arise, the operator negotiates with the stakeholders to find a solution that prioritizes critical maneuvers while considering assured science and technological demonstration needs.

From Reservation to Execution - Orchestrating the Maneuver: As the reserved window nears the 24-hour mark, the system creates a concrete maneuver activity using the latest ITASAT2 data and the refined reservation parameters. This activity serves as the definitive plan for the maneuver.

Throughout the maneuver execution, the operator closely monitors ITASAT2. Should the satellite deviate from the planned trajectory, the operator's judgment becomes essential. They assess the situation and determine if corrective actions are necessary to ensure the maneuver's success.

Learning from Every Maneuver - Post-Maneuver Analysis: Following the maneuver, a crucial step involves analyzing the actual ITASAT2 orbit compared to the planned one. The operator leads this analysis, identifying any discrepancies and their potential causes. This information is vital for future maneuver planning and orbit corrections for ITASAT2.

By combining the power of maneuver reservations with the unparalleled expertise of a human operator, this strategy ensures informed decision-making throughout the ITASAT2 maneuver process. This collaborative approach is vital for the success of the mission and the well-being of the satellite.

CONCLUSIONS AND FUTURE WORK

Lessons learned from the operations of the ITASAT and SPORT missions served as the foundation for conceptualizing the ITASAT2 mission operations. This mission has led CEI to study an operational scenario that includes enhanced automation strategies to advance CubeSat operations. These preliminary designs aim to optimize mission operations by streamlining routine tasks, reducing the need for manual intervention, and effectively utilizing ground station resources. Key anticipated outcomes include the implementation of automated processes for telecommunications and data handling, as well as the development of a scalable operational framework supported by Ground Station as a Service (GsaaS). As the project progresses, these strategies and frameworks will continue to be refined and tested.

In the realm of CubeSat operations, where size, weight, and power constraints are particularly stringent, leveraging automation presents both challenges and opportunities. Onboard, CubeSats can implement basic automation tasks such as attitude control, power management, and simple data collection routines, all crucial for autonomous operation within the confines of the spacecraft's limited resources. Additionally, rudimentary decision-making processes, like hazard avoidance maneuvers based on predefined algorithms, can enhance CubeSat autonomy.

However, due to the limitations in computational capacity, more sophisticated tasks requiring extensive processing power or continuous learning capabilities may be impractical onboard. Here, ground systems play a pivotal role. They can analyze the vast datasets collected by CubeSats, employing complex machine learning algorithms for in-depth analysis, predictive modeling, and adaptive decision-making. Ground-based automation can also facilitate real-time monitoring, anomaly detection, and corrective actions, leveraging the computational resources and flexibility unavailable onboard. Thus, while CubeSats can execute fundamental autonomous functions, the bulk of advanced automation, enabled by machine learning and complex algorithms is best executed by ground systems with ample processing power and scalability.

Considering the lessons learned from CEI's previous mission and the challenge of operating three CubeSats in orbit and a deep space mission SelenITA, analyzing the implementation of automation and machine learning sounds mandatory for the feasibility of the missions.

Future work will focus on refining exception-handling processes, particularly during the mission's early phases, by developing advanced algorithms for real-time anomaly detection. Additionally, exploring the use of machine learning could further enhance automation efficiency and reliability. Other areas of future research include improving inter-satellite communication within the ITASAT2 formation and optimizing ground segment infrastructure to support the demands of future CubeSat missions. Extensive testing and validation of these strategies will be crucial to ensure their robustness and reliability before full deployment.

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ITA Space Center (CEI) Project Team

Project Manager: Luís Eduardo Vergueiro LOURES da Costa.

Technical Coordinator: LIDIA Hissae Shibuya Sato. *Deputy Technical Coordinator:* RENAN Guilherme Soares Menezes.

Execution team (in alphabetical order): ADRIANO César de Sousa Pereira; ANA CAROLINA Di Iorio Jeronymo; ANA Carolina Lima; BRUNO Leonardo Schuster; CARLA Juren Lucas; CLÉBER Toss Hoffmann; DEBORA Cristina Alves dos Santos Siqueira; DENIS Guilgim Vieira; Douglas Estevam CASALE; DOUGLAS Luan Cardoso Arena; EDSON Wander do Rego Pereira; FELIPE Oliveira Tavares; ISABELA dos Santos Pereira; LUIS FELIPE Camponogara; MARIA EDUARDA Mora Camino-Priante; MAUREN Walter D'Avila; PAULL Cristhian Acosta Mendoza; PRISCILA Eduarda Kraft Lopes; RODOLFO Guilherme Wottrich; SONIA Aparecida de Sousa; THADEU Augusto Medina de Carvalho; UZIEL Parada Nunes; VICTOR Oliveira Costa; VICTÓRIA de Souza Rodrigues; VINICIUS Hardt Schreiner

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