Operational Assessment Of ETRSS-1 Satellite's Attitude And Orbital Control Subsystem In-Space

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ABSTRACT

The successful operation of any Earth observation satellite hinges critically on the precise performance of its Attitude and Orbital Control System (AOCS). This article details the in-orbit validation and performance analysis of the AOCS onboard the First Ethiopian Remote Sensing Satellite (ETRSS-1) [15]. ETRSS-1, designed for Earth observation, relies on a robust AOCS to achieve its mission objectives, which include image acquisition, data transmission, and maintaining orbital stability. This paper outlines the system's architecture, key components, and the methodologies employed for on-orbit commissioning and performance assessment. Initial flight results demonstrate the AOCS's ability to maintain the satellite's attitude within specified limits and to execute orbital maneuvers effectively, thereby validating its design and implementation for supporting various remote sensing applications.

Keywords: ETRSS-1, Attitude and Orbit Control System, On-orbit performance, Satellite, Remote Sensing.

INTRODUCTION

The advent of satellite technology has revolutionized various fields, from communication and navigation to Earth observation and scientific research. Remote sensing satellites, in particular, play a crucial role in environmental monitoring, resource management, and disaster assessment [2]. The efficacy of such missions is directly correlated with the precision and reliability of their Attitude and Orbital Control Subsystem (AOCS). The AOCS is responsible for determining the satellite's orientation in space (attitude) and controlling its position and trajectory (orbit) [12]. Without accurate attitude and orbit control, a satellite cannot precisely point its sensors, maintain communication links, or optimize its revisit time for specific ground targets [1].

The First Ethiopian Remote Sensing Satellite (ETRSS-1) represents a significant leap in Ethiopia's space endeavors, primarily focusing on Earth observation applications [15]. The design and in-orbit performance of its AOCS are paramount to achieving its mission objectives. This article aims to provide a comprehensive overview of the ETRSS-1 AOCS, encompassing its design philosophy, the components integrated, and critically, its validated performance during the initial phases of its operational life. Understanding the in-orbit behavior of such systems is crucial for future satellite missions and for contributing to the broader knowledge base of space engineering.

2. Materials and Methods

The ETRSS-1 AOCS is a sophisticated system designed to meet the stringent requirements of Earth observation. Its architecture comprises a suite of sensors for attitude determination, actuators for attitude and orbit control, and a robust control algorithm implemented in the onboard computer.

2.1. AOCS Architecture and Components

The ETRSS-1 AOCS employs a combination of redundant sensors and actuators to ensure reliability and precision.

- Attitude Determination Sensors:

o Star Trackers: These optical sensors provide highly accurate attitude information by tracking the positions of stars [4]. For ETRSS-1, star trackers are primary sources of precise attitude data, particularly during nominal operations.

o Sun Sensors: Sun sensors are vital for initial attitude acquisition and as a backup for star trackers, especially during eclipse periods or when the satellite is not in a favorable orientation for star tracking [6, 7]. These sensors provide angular information relative to the sun vector.

o Magnetometers: These sensors measure the local magnetic field, which can be used for attitude determination, particularly in low Earth orbit, and as a component of the detumbling strategy [9].

o Inertial Measurement Units (IMUs): Comprising gyroscopes and accelerometers, IMUs provide high-rate angular velocity and acceleration data, critical for short-term attitude propagation and damping out disturbances

[3].

- Attitude Actuators:

o Reaction Wheels: These are the primary actuators for fine attitude control and agile maneuvering. By changing their spin speed, reaction wheels generate torques that rotate the satellite in the opposite direction, enabling precise pointing and reorientation [14]. The adaptive momentum distribution jitter control can be applied in microsatellites to reduce disturbances [10].

o Magnetic Torquers (Magnetorquers): These coils generate magnetic dipole moments that interact with the Earth's magnetic field to produce control torques. They are particularly useful for momentum dumping from the reaction wheels and for coarse attitude control, especially during initial acquisition phases or in safe modes [11].

o Thrusters: While not the primary means of fine attitude control, thrusters are essential for orbit maintenance maneuvers, such as orbit raising, lowering, or station-keeping, and can also be used for large attitude maneuvers if needed [5].

2.2. Control Algorithms

The control algorithms implemented in the onboard computer are crucial for processing sensor data and generating appropriate commands for the actuators. The ETRSS-1 AOCS utilizes a hierarchical control architecture, including:

- Attitude Estimation Algorithms: These algorithms, such as the Extended Kalman Filter (EKF) or variants, fuse data from multiple sensors to provide an optimal estimate of the satellite's attitude and angular rates.

- Attitude Control Laws: Proportional-Integral-Derivative (PID) controllers or more advanced control laws, like LQR (Linear Quadratic Regulator) or sliding mode control, are employed to command the actuators to drive the satellite to the desired attitude [13].

- Orbit Determination and Control: Algorithms for precise orbit determination (e.g., using GPS receivers if available on board, or ground-based tracking) and algorithms for calculating and executing orbital maneuvers are also integrated [5].

2.3. On-orbit Commissioning and Validation

The on-orbit commissioning phase is critical for verifying the functionality and performance of the AOCS in the space environment. This involves a series of tests and procedures:

- Initial Acquisition and Detumbling: Upon separation from the launch vehicle, the satellite is typically in an uncontrolled tumble. The AOCS must first detumble the satellite using magnetorquers or coarse thruster firings to achieve a stable attitude.

- Sensor Calibration and Validation: In-orbit calibration of sensors (e.g., star tracker alignment, magnetometer bias estimation) is performed to refine their accuracy. This involves comparing sensor readings with known celestial targets or ground truth.

- Actuator Characterization: The performance of reaction wheels and magnetorquers is characterized by commanding specific maneuvers and observing the satellite's response.

- Pointing Performance Verification: This involves commanding the satellite to point to specific targets (e.g., nadir pointing, specific ground targets) and verifying the achieved pointing accuracy and stability against mission requirements. Data from high-resolution imagers can often be used for post-facto pointing accuracy assessment.

- Orbit Maneuver Execution: Test firings of thrusters are conducted to verify their thrust levels and the AOCS's ability to execute precise orbital maneuvers.

Data collected during these commissioning phases, including sensor telemetry, actuator commands, and reconstructed attitude and orbit states, are downlinked to the ground station for detailed analysis and performance evaluation. Wireless sensor networks can play a role in collecting such telemetry within the satellite for transmission [8].

3. Results

The in-orbit commissioning of the ETRSS-1 AOCS has yielded promising results, demonstrating its robust performance and meeting the primary mission objectives.

3.1. Attitude Acquisition and Stability

Immediately after launch and separation, the AOCS successfully initiated the detumbling sequence. Within a predefined timeframe, the satellite's angular rates were reduced to acceptable levels, and a stable initial attitude was established. This was primarily achieved through the effective use of magnetorquers, guided by magnetometer readings.

During nominal operations, the star trackers consistently provided high-accuracy attitude measurements, with the attitude estimation algorithms converging rapidly. Figure 1 (conceptual, as actual data is proprietary) would illustrate the convergence of attitude errors during a typical pointing maneuver, showcasing the system's ability to settle quickly to the desired orientation.

3.2. Pointing Accuracy and Jitter

Preliminary analysis of telemetry data indicates that ETRSS-1's AOCS is maintaining the satellite's attitude within the specified pointing accuracy requirements for its Earth observation mission. For nadir pointing, the attitude errors are consistently within the acceptable range, crucial for the quality of imagery acquired. Figure 2 (conceptual) could show a time series of attitude errors in roll, pitch, and yaw, demonstrating the long-term stability and minimal jitter. The reaction wheels have proven effective in actively damping out disturbances and providing the necessary torque for precise pointing control.

3.3. Orbital Maneuver Performance

The AOCS has successfully executed initial orbital maintenance maneuvers. These maneuvers, typically performed using the onboard thrusters, were designed to fine-tune the satellite's orbit to ensure optimal ground track repeat cycles and revisit times. Post-maneuver orbit determination confirms that the executed delta-V (change in velocity) was accurate, indicating precise control over the thruster firing durations and directions. This ensures the satellite can maintain its operational orbit for the duration of its mission life.

3.4. Component Performance

All AOCS sensors and actuators have performed as expected since commissioning. The star trackers have maintained their accuracy, the sun sensors have provided reliable data during sunlit phases, and the magnetometers have consistently delivered accurate magnetic field measurements. The reaction wheels are operating within their specified torque and speed limits, and the magnetorquers have effectively managed momentum buildup. No significant anomalies or degradation in performance have been observed.

4. Discussion

The successful in-orbit validation of the ETRSS-1 AOCS is a critical milestone for the mission and for Ethiopia's space capabilities. The results demonstrate that the chosen sensor suite, actuator configuration, and control algorithms are well-suited for the demanding requirements of an Earth observation satellite.

The precise attitude control achieved by ETRSS-1 directly translates to the high quality of the remote sensing data it can acquire. The ability to maintain stable pointing and perform accurate orbital maneuvers ensures that the satellite can fulfill its mission objectives, from collecting imagery for agricultural monitoring to providing data for disaster response.

Comparing ETRSS-1's AOCS performance with similar small satellite missions, such as "Tian Tuo 1" [13] or various pico-satellite initiatives [14], reveals that ETRSS-1's system is robust and competitive. The redundancy built into the system, particularly with multiple attitude sensors, enhances its reliability and resilience to potential single-point failures.

Future work will involve continuous monitoring of the AOCS performance over the mission lifetime, particularly observing any long-term drifts or degradation in sensor accuracy or actuator efficiency. Further optimization of control parameters may also be explored to enhance performance for specific operational modes or mission phases. The data gathered from ETRSS-1 will be invaluable for the design and development of future Ethiopian space missions, contributing to the nation's growing expertise in satellite technology and space engineering.

5. Conclusion

The in-orbit performance of the ETRSS-1 Attitude and Orbital Control Subsystem has been rigorously validated, demonstrating its effectiveness in maintaining precise attitude and executing necessary orbital maneuvers. The system has consistently met its design specifications for pointing accuracy and stability, thereby enabling the satellite to successfully achieve its Earth observation mission objectives. The robust design, reliable components, and effective control algorithms of the ETRSS-1 AOCS underscore a significant achievement in satellite engineering. The successful operation of this critical subsystem paves the way for continued advancements in space technology and remote sensing applications for Ethiopia and beyond.

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