Development of the MOCI ADCS-01 Verification Test

Rinisha Ramprakash, Wali Mian, Deepak R. Mishra
rinisha.ramprakash@uga.edu, wali.mian@uga.edu, dmishra@uga.edu
Small Satellite Research Laboratory, University of Georgia

Requirement

Reaction wheels shall be able to rotate its mass fast enough to keep the distance between the ground target and the center of the primary imager's FOV within 25% of the distance that makes up the primary imager's FOV nadir ground coverage.

Objective

Determine if the ADCS unit (MAI-401) can perform slew maneuvers to achieve sufficient overlap between consecutive images for a structure-from-motion pipeline.

Abstract

The members of the Guidance and Navigation Control team (GNC), whose primary goal is to calculate the commands needed to steer the Cubesat where it is desired to be, determine the CubeSat's orbital parameters such as the positions, and adjust the path of the CubeSat to meet mission requirements, will be conducting research at the University of Georgia Small Satellite Research Laboratory (SSRL). This research will be focused on helping test the Attitude Determination Control System (ADCS) of the Multiview Computational Onboard Imager (MOCI) CubeSat, which is a system that is responsible for determining and maintaining the orientation of the CubeSat. According to the University Nanosatellite Program (UNP), which is the lab's primary stakeholder, the purpose of the ADCS Verification Test, which is a test that ensures the CubeSat points in the desired nadir direction for capturing accurate images of specific areas such as coastal areas on the Earth's surface. Under this ADCS verification test, there are eight requirement verification methods (RVM). The research examines the first verification test, ADCS-01. ADCS-01 is a verification test to verify that the Cubesat's wheels moved at the requested speed and that it commanded the wheels to spin. ADCS-01 states that the reaction wheels shall be able to rotate fast enough to keep the maximum boresight error within 25% of the distance that makes up the primary imager's field of view (FOV) nadir ground coverage.

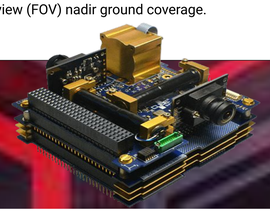

Figure 1: Example of the figure ADCS

Motivation

The primary purpose of this research is to explore and verify the requirements of the ADCS-01. This includes confirming that the reaction wheels rotate at the requested speed to maintain boresight error with 25% of the FOV nadir ground coverage. The research will involve various methods, including gyroscopes, to validate that the CubeSat's reaction wheels function properly and assess their aptitude to achieve accurate pointing and imaging capabilities. Some general steps towards verifying this requirement could be understanding the system parameters, such as clearly defining the characteristics of your primary imager, including its field of view, nadir ground coverage, and any specific constraints on boresight error, considering the effects of reaction wheels, and disturbances. Gyroscopes are a method that can be commonly used for measuring angular rates and provide valuable data for assessing the rotational capabilities of the reaction wheels. Utilizing the Earth Observing System (EOS) to locate orbital parameters will aid in establishing a clear understanding of the CubeSat's position in orbit. To verify the requirement for the ADCS-01, we need to further experiment with more methods to ensure that the reaction wheels of the CubeSat rotate fast enough, for the CubeSat to be oriented for capturing full coverage of the nadir ground.

Method and Tools

The verification test ADCS-01 was designed to confirm that the reaction wheels can rotate at the required speeds to maintain the primary imager's boresight within acceptable limits.

Key methods and tools used include:

- **Gyroscopes:** Measure angular rates.
- **Earth Observing System (EOS):** Locate orbital parameters.
- **Spreadsheets:** Perform detailed calculations and analyze boresight error.
- **ADCS Unit (MAI-401):** Execute and measure slew maneuvers.
- **Simulation Models:** Predict and verify ADCS performance under various conditions.

Parameters Evaluated:

- **Max Slew Rate [deg/sec]:** Determines the speed at which the reaction wheels can rotate.
- **Max Angular Acceleration [deg/(sq. sec)]:** Measures how quickly the reaction wheels can change the rotation speed.
- **ADCS Torque [mN m]:** Measures the torque produced by the ADCS unit.
- **Inertia [kg (sq. m)]:** Includes Ixx, Iyy, and Izz, representing the satellite's resistance to angular acceleration.
- **Momentum Storage [mN m sec]:** Total momentum storage capacity of the ADCS unit.

Test Procedure:

1. **Setup:**
   - Calibrate the ADCS unit (MAI-401) using gyroscopes and EOS.
   - Configure the simulation models with relevant parameters such as altitude, viewing angle, and initial conditions.
2. **Measurement:**
   - Conduct tests to measure the max slew rate and max angular acceleration in three axes (xx, yy, zz).
   - Record the ADCS torque and inertia values.
3. **Error Calculation:**
   - Use spreadsheets to calculate the boresight error based on the measured angular rates and viewing angles.
   - Perform error analysis for both overhead and side angle cases.
4. **Performance Evaluation:**
   - Compare the calculated boresight error with the allowable FOV nadir ground coverage.
   - Evaluate the ADCS unit's performance across different altitudes and viewing angles.

Calculations and Tools:
Calculations were performed using a detailed spreadsheet, which can be accessed here:

Results

Imager FOV and Boresight Calculation:

Imager FOV = 4.89 degrees
Allowable boresight = FOV nadir coverage = 2*Altitude*tan(FOV) = 68.444 km (at 400 km altitude)

Results and Analysis

Overview: Calculations ensured that the boresight ground error remains within 25% of the imager's FOV nadir ground coverage. Various altitudes and viewing angles were tested to validate accuracy.

Max Slew Rate [deg/sec]		Max Angular Acceleration [deg/(sq. sec)]	
xx	1.333	xx	0.093
yy	3.412	yy	0.237
zz	1.834	zz	0.127

Figure 2: Maximum Slew Rate and Angular Acceleration of the ADCS Unit

ADCS Torque [mN m]	0.769	Ixx [kg (sq. m)]	Iyy [kg (sq. m)]	Izz [kg (sq. m)]
Momentum Storage [mN m sec]	11.076	0.476	0.186	0.346

Figure 3: ADCS Torque and Inertia Specifications And Momentum Storage Capacity of the ADCS Unit

Case Studies:

Case 1: Overhead			
Error Source	Error Type	Error Value	Boresight Ground Error [m]
GPS	Position [m]	10.000	10.000
ADCS Knowledge	Angle	0.100	698.132
Mechanical Alignment	Angle [arcsec]	1.000	1.939
Thermal	Angle [arcsec]	3.000	5.818
ADCS Accuracy	Angle	0.2	1396.269073
Total			2112.159

Figure 4: Boresight Error Assessment for Overhead Viewing Angle

Case 2: Side Angle				
Error Source	Error Type	Error Value	Boresight Normal Error [m]	Boresight Ground Error [m]
GPS	Position [m]	10.000	9.659	10.000
ADCS Knowledge	Angle	0.100	698.132	722.760
Mechanical Alignment	Angle [arcsec]	1.000	2.002	2.073
Thermal	Angle [arcsec]	3.000	6.007	6.219
ADCS Pointing	Angle	0.2	1396.269073	1445.524
Total				2186.576

Figure 5: Boresight Error Evaluation for Side Viewing Angle

Max Boresight Ground Error (m)	FOV nadir ground coverage (km)	Altitude (km)	Max Viewing Angle (degrees)
31.208	68.44354298	400	20
32.743	68.44354298	400	25
35.114	85.55442872	500	15
36.478	85.55442872	500	20
38.379	85.55442872	500	25
42.608	111.2207573	650	15
44.359	111.2207573	650	20
46.795	111.2207573	650	25

Figure 6: Comparative Boresight Error at Different Altitudes and Angles

Discussion

Interpretation: The results indicate that the maximum boresight ground error for the ADCS unit is consistently less than the imager's nadir FOV ground coverage across various altitudes and viewing angles. This confirms that the ADCS unit is capable of maintaining precise imaging requirements.

Implications: The ability of the ADCS unit to perform precise slew maneuvers ensures reliable image overlap, which is crucial for applications such as the structure-from-motion pipeline. This capability enhances the overall imaging quality and reliability of the satellite system.

Conclusion

Summary: The ADCS unit (MAI-401) meets the necessary requirements to perform accurate slew maneuvers, ensuring that the distance between the ground target and the center of the primary imager's FOV remains within acceptable limits. This capability supports the structure-from-motion pipeline and other imaging applications.

Future Work: Further testing at different altitudes and viewing angles can be conducted to refine the performance of the ADCS unit. Additionally, improvements in ADCS technology can be explored to enhance precision and reliability further.

References

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