Testing and Simulation of Multiview Onboard Computational Imager CubeSat

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I. Abstract

MOCI, a 6U CubeSat, is designed for monitoring the health and productivity of coastal wetlands through the utilization of high-resolution imagery employing structure from motion (SfM) techniques. We believe that this mission holds the potential to advance technologies by enabling the passive generation of three-dimensional point clouds resistant to tampering. Additionally, MOCI aims to foster community outreach initiatives by establishing robust foundations for STEM education and training among students. As part of the project and lead for Guidance, Navigation, and Control (GNC) team, we are tasked with overseeing the completion of eight verifications essential for UNP's approval to proceed to the pre-launch stage. These verifications primarily focus on orbital simulations to ensure MOCI's maneuverability meets the required standards and can effectively respond to emergency scenarios by activating its ADCS system to counteract anomalies. Currently, MOCI is in its integration phase, and our primary stakeholder, the University of Nanosatellite Program, has provided stringent guidelines to ensure thorough verification before advancing to the pre-launch phase and subsequent deployment into low Earth orbit. We are conducting orbital simulations utilizing specialized software developed by Cubespace Satellite Systems to authenticate the functionality of our ADCS subsystem. Specifically, we are tasked with optimizing the slewing maneuverability necessary for MOCI to track its designated targets during each orbit. This effort supplements the ADCS verification procedures, particularly those outlined in ADCS-03, mandating the ability to point the payload to specified ground targets, and ADCS-06, necessitating the utilization of fine attitude knowledge during slew maneuvers. Subsequently, the SSRL MOCI team will undergo a pre-integration review with UNP to evaluate our findings and ensure the accuracy of our collected data.

II. Introduction

Coastal wetlands play a crucial role in maintaining ecological balance, protecting coastal lines from erosion, and serving as habitats for diverse species. Monitoring these areas is essential for understanding and mitigating the impacts of climate change and human activity. However, traditional monitoring methods are often limited by accessibility, coverage, and the dynamic nature of these environments. The advent of CubeSat technology offers a new paradigm in environmental monitoring, combining cost-efficiency with advanced observational capabilities.

MOCI is at the forefront of this technological shift. Designed to monitor the health and productivity of coastal wetlands, MOCI employs high-resolution imagery and Structure from Motion (SfM) techniques to generate detailed 3D point clouds. This innovative approach not only advances the field of remote sensing but also provides a robust platform for STEM education and community outreach, engaging students in hands-on learning experiences.

As the project lead for the GNC team, our focus is on ensuring MOCI's readiness through a series of critical verifications for the UNP approval. This includes producing orbital simulations and the optimization of the ADCS for precise maneuverability and target tracking. Our efforts are essential in preparing MOCI for its mission, demonstrating the potential of CubeSats in environmental monitoring and beyond.

III. Objectives and Goals

The core objective of our research is focused on the advancements and verifications of the ADCS functionalities, specifically through the ADCS-03 and ADCS-05 verifications. These are critical for ensuring MOCI's precision in high-resolution imaging and 3D point cloud generation for coastal wetland health assessment. The ADCS-03 verification involves ensuring that MOCI can accurately point its payload to specific ground targets, a necessity for the detailed environmental monitoring capabilities of the satellite. The ADCS-05 research can be assumed to similarly focus on enhancing MOCI's attitude control and maneuverability for effective environmental observation.

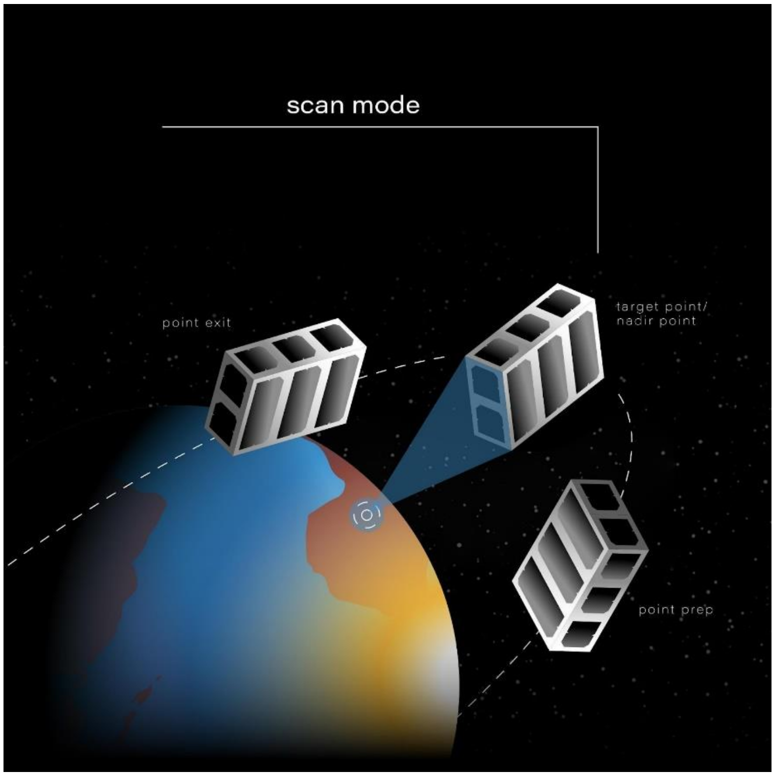

Fig. 1 Visual Representation of Scan Mode

Alongside these primary research goals, MOCI's mission also aims to leverage these technological advancements to foster community outreach and STEM education initiatives. By integrating state-of-the-art satellite technology into environmental monitoring efforts, MOCI provides a platform for engaging students and the community in STEM, highlighting the practical applications of satellite technology in addressing global environmental challenges.

While the broader mission of MOCI encompasses a wide range of objectives from environmental monitoring to community engagement, the focus of this manuscript is on the critical role of ADCS-03 and ADCS-05 verifications in enhancing MOCI's capabilities for precise and effective environmental observation.

IV. Methodology

Our research methodology utilized the EOS software developed by Cubespace for the dynamic simulation of MOCI's ADCS capabilities in a realistic orbital environment. This approach integrates atmospheric conditions, disturbances, and other critical factors to evaluate the ADCS system's performance, particularly focusing on ADCS-03 and ADCS-05 verifications. Unlike traditional orbital simulation tools, the EOS software offers specialized ADCS testing functionalities, allowing for the precise control and verification of Cubespace-manufactured ADCS components.

This methodology marks a novel venture for the University of Georgia's SSRL, transitioning from generic orbital simulation software to the ADCS-specific capabilities of the EOS platform. Through scripted events in EOS, we conducted targeted ADCS capability tests, aligning with MOCI's mission objectives, such as ground-tracking mountain peaks. Our process involved scripting XML files for sequence events like point prep, image acquisition, and point exit, with a focus on verifying ADCS performance during these critical mission stages.

This approach not only advances our understanding of ADCS system limits but also contributes to our STEM outreach goals by educating lab members on ADCS subsystem intricacies. This dual focus underscores the significance of our research in enhancing satellite mission planning and execution while fostering educational growth in space technology.

V. Current Simulations

Our recent endeavors in EOS simulations have led to the development and testing of multiple XML scripts, incorporating MOCI's target list of mountain peaks globally. Under my leadership, a dedicated team of three simulation specialists within the GNC division has crafted, evaluated, and simulated a series of scenarios aligned with this objective. A snippet from our current XML script, as illustrated below, highlights the strategic scheduling of 80 targets for MOCI's slewing operations, adhering to the stringent requirements of our pointing budget. This script, a product of the simulation team's collective effort, generates an Excel file documenting key variables for subsequent GNC team analysis and UNP interim review preparation.


```xml
▼<SchedulerScript xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <UpdateVisual>true</UpdateVisual>
 ▼<ScheduledSettings>
    <ScheduledPropertySet Time="0" ObjectId="CubeACP" Property="EstimationMode" Value="EkfFullState"/>
    <ScheduledPropertySet Time="0" ObjectId="CubeACP" Property="ControlMode" Value="RwTargetTrack"/>
    <!--  Slewing maneuver to target: Mount Everest  -->
    <ScheduledPropertySet Time="300" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:2706.2245650291425, LatRef:1271.5175677017123, AltRef:10}"/>
    <!--  Slewing maneuver to target: Aconcagua  -->
    <ScheduledPropertySet Time="600" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-2228.6365966796875, LatRef:-1516.770612526686, AltRef:10}"/>
    <!--  Slewing maneuver to target: Denali  -->
    <ScheduledPropertySet Time="900" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-4740.00670875, LatRef:2845.287454166667, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mount Kilimanjaro  -->
    <ScheduledPropertySet Time="1200" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:1149.9121589660617, LatRef:-150.51653766245, AltRef:10}"/>
    <!--  Slewing maneuver to target: Pico Cristóbal Colón  -->
    <ScheduledPropertySet Time="1500" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-2324.4673614501953, LatRef:454.42842171694974, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mount Logan  -->
    <ScheduledPropertySet Time="1800" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-4394.688997083334, LatRef:2742.238608888889, AltRef:10}"/>
    <!--  Slewing maneuver to target: Pico de Orizaba  -->
    <ScheduledPropertySet Time="2100" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-3046.1124496459943, LatRef:859.3526504742986, AltRef:10}"/>
    <!--  Slewing maneuver to target: Vinson Massif  -->
    <ScheduledPropertySet Time="2400" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-2773.765301666667, LatRef:-3591.0317980555556, AltRef:10}"/>
    <!--  Slewing maneuver to target: Puncak Jaya  -->
    <ScheduledPropertySet Time="2700" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:4236.768524169922, LatRef:-195.39430840868044, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mount Elbrus  -->
    <ScheduledPropertySet Time="3000" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:1298.5869903564453, LatRef:1946.4721812211574, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mont Blanc  -->
    <ScheduledPropertySet Time="3300" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:170.38973999023438, LatRef:2045.877787253734, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mount Damavand  -->
    <ScheduledPropertySet Time="3600" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:1603.3939666748047, LatRef:1621.3888239236385, AltRef:10}"/>
    <!--  Slewing maneuver to target: Klyuchevskaya Sopka  -->
    <ScheduledPropertySet Time="3900" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:5003.8860816955275, LatRef:2540.0758367756125, AltRef:10}"/>
    <!--  Slewing maneuver to target: Nanga Parbat  -->
    <ScheduledPropertySet Time="4200" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:2314.6673889160156, LatRef:1587.8834409375213, AltRef:10}"/>
    <!--  Slewing maneuver to target: Mauna Kea  -->
    <ScheduledPropertySet Time="4500" ObjectId="CubeACP" Property="TrackingTarget" Value="{LongRef:-4857.666411876662, LatRef:902.0978209443783, AltRef:10}"/>
```


Fig. 2 XML Script Snippet

Leveraging the EOS software's robust capabilities, our script simulations reveal diverse behaviors within the target tracking mode. The software's estimation mode, crucial for our analysis, facilitates precise attitude and pointing error estimations—integral components of our pointing budget. This not only underscores the operational alignment with our concept of operations but also serves as an educational tool for GNC team members, particularly newcomers, to familiarize themselves with ADCS intricacies.

Fig. 3 Orbital Simulation Software Interface

The EOS interface, depicted above, provides a comprehensive overview of the user experience during ADCS system simulations. This insight into the software's functionality not only demonstrates its application in simulation tasks but also highlights its utility in educating GNC team members about ADCS operations and the implementation of our pointing budget.

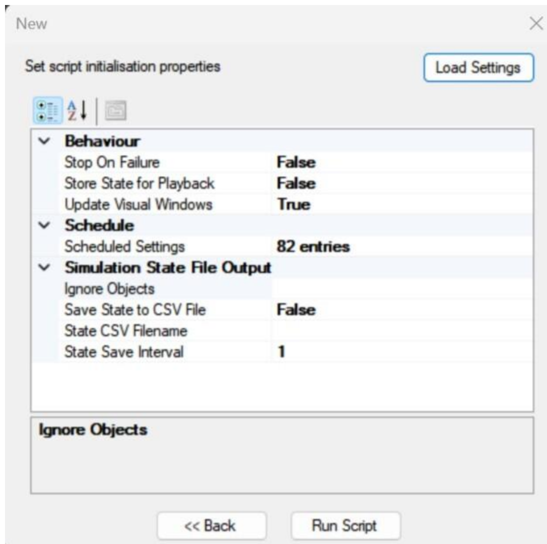

Fig. 4 XML Script Loading Process

Upon code integration, users are prompted to initiate a new simulation, facilitating the upload and execution of the script. This process underscores the software's user-friendly design, enabling efficient simulation management and offering a hands-on learning experience for team members.

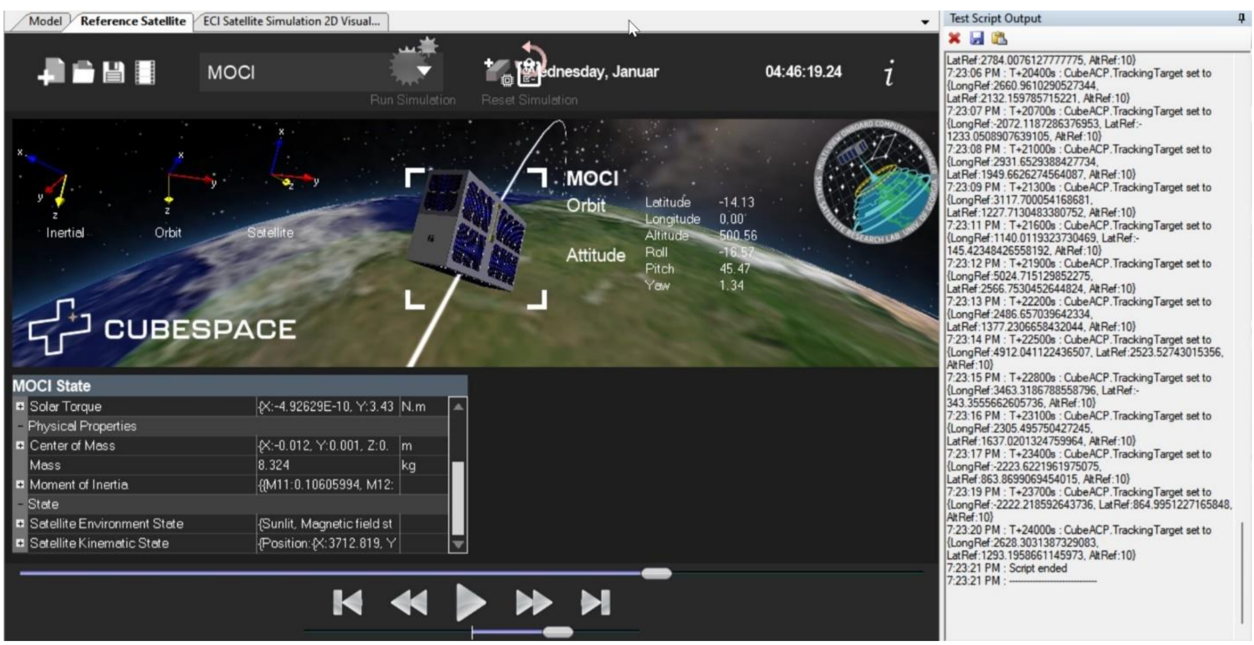

Fig. 5 Running Script Interface

The simulation's output, particularly the Excel file, serves as a cornerstone for our analytical process, allowing us to dissect and understand the nuances of MOCI's ADCS performance. The data extracted, ranging from angular velocities to pointing accuracies, provides a multidisciplinary view of the system's operational fidelity against the mission's objectives. This iterative process of simulation, data collection, and analysis forms the foundation of our verification strategy, ensuring that each ADCS component operates within its optimal parameters.

Furthermore, the evolution of our simulation practices, from the initial use of generic orbital software to the specialized EOS platform, highlights a significant leap in our capability to model complex satellite behaviors accurately. This transition not only enhances our technical proficiency but also aligns our research with cutting-edge practices in satellite simulation. Looking ahead, we plan to refine our simulation models further, incorporating more dynamic environmental interactions, exploring the potential impacts of unforeseen orbital events on ADCS performance, and efficiently combining the target tracking list to match the projected orbit of MOCI during its launch phase. This proactive approach aims to fortify MOCI's resilience and reliability, ensuring its success in the demanding realm of space operations.

VI. Conclusion

Our research has embarked on an educational journey to assess the ADCS capabilities of MOCI using the EOS software provided by CubeSpace. This endeavor is pivotal for ensuring that MOCI can accurately perform its mission-critical tasks, including high-resolution imaging of coastal wetlands and generating detailed 3D point clouds using Structure from Motion techniques. The ongoing simulation efforts, as outlined in the RVM items, represent a meticulous approach to validating the ADCS's performance under realistic orbital conditions, accounting for atmospheric disturbances, gravitational effects, and the satellite's interaction with Earth's magnetic field.

The preliminary findings from our simulations hold promise, indicating that MOCI's ADCS system is well on its path to meeting the stringent requirements set forth by ADCS-03 and ADCS-05. However, it's imperative to acknowledge that our work is not yet complete. The nature of this research, encompassing complex dynamic modeling and simulation, necessitates a continuous process of evaluation and refinement.

Looking ahead, our research will focus on completing the verification of all ADCS related RVM items. This will involve an iterative process of simulation, analysis, and adjustment to ensure that every aspect of MOCI's ADCS system aligns with the operational demands of its mission. Further, we will extend our simulation efforts to encompass additional scenarios that MOCI might encounter in its orbital environment, thereby enhancing the robustness and reliability of its ADCS system.

Acknowledgments

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References

The following pages are intended to provide examples of the different reference types. All references should be in 9-point font, with the first line flush left and reference numbers inserted in brackets. You are not required to indicate the type of reference; different types are shown here for illustrative purposes only. The DOI (digital object identifier) should be incorporated in every reference for which it is available (see Ref. 1 sample); for more information on DOIs, visit www.doi.org or www.crossref.org.

[1] Cubespace, "EOS Simulator Software Package," Ver. 1.13, Cubespace, Stellenbosch, South Africa, Nov. 2022.
[2] University Nanosatellite Program, UNP Mission Concept User Guide, Air Force Research Lab, Bernalillo County, New Mexico, May 2023.