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VALIDATION OF LUNAR LANDER TEST VEHICLE SIMULATION USING TEST DATA AND RESULTS

Abstract

This study presents the development, simulation, optimization, and validation of a lunar lander test vehicle equipped with a cold gas propulsion system, including one EGC (Earth Gravity Cancellation) thruster, four main thrusters and four RCS thrusters. The simulation replicates the real system by integrating a high-fidelity rocket plant model, atmospheric and external force models, a suspension model, and a propulsion system model. The primary objective is to evaluate the lander's performance under realistic conditions, refine its control strategies, test GNC algorithms, and identify potential system errors before physical testing.

A key contribution of this research is the systematic validation of the simulation using real test data. Multiple validation techniques, including trajectory reconstruction, error minimization through sensor fusion, and model parameter tuning, were employed to ensure high-fidelity replication of the actual flight dynamics. Comparative analysis between simulated and real-world flight data was performed using statistical error metrics such as RMSE (Root Mean Square Error) and correlation coefficients, ensuring an accurate prediction of system behavior. Additionally, Monte Carlo simulations were used to assess robustness under varying initial conditions and external disturbances.

To enhance the accuracy and reliability of the validation process, AI-driven optimization techniques were employed for model verification and parameter estimation. Neural networks were trained on test data to refine system parameters, allowing the simulation to adapt dynamically based on real-world behavior. Additionally, reinforcement learning algorithms were integrated to improve control policies by iteratively adjusting parameters based on simulated flight outcomes. Machine learning models were also used for anomaly detection, identifying discrepancies between the simulation and real test data to refine system accuracy. These AI-driven techniques ensured that the simulation closely aligned with real-world conditions, improving predictive accuracy and enabling adaptive tuning of control strategies under different scenarios.

This methodology not only enhances the reliability of the landing system but also significantly reduces the costs associated with physical prototyping and testing. Furthermore, the simulation enables the study of lunar gravity and environmental conditions, which are impossible to replicate on Earth. The results of this study demonstrate that a validated and AI-optimized simulation framework can serve as a critical tool in the development and testing of future lunar landing missions.