28th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM (A5)
Interactive Presentations - 28th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM (IP)

Author: Mr. Raúl Gianmarco Chávez Chávez
Universidad Nacional de Ingeniería (Lima, Perù), Peru

MODEL REFERENCE ADAPTIVE CONTROL FOR ROBUST TRAJECTORY TRACKING IN LUNAR LANDING MISSIONS UNDER UNCERTAIN TERRAIN CONDITIONS

Abstract

Lunar landing missions require precise trajectory tracking despite uncertainties such as uneven surfaces and spacecraft mass variations due to fuel consumption. Model Reference Adaptive Control (MRAC) is a promising approach that adjusts control parameters in real time to match a desired reference model. However, existing MRAC methods often lack integration with terrain estimation and struggle with abrupt changes in system dynamics. This work proposes a novel MRAC framework incorporating terrain estimation and adaptive gains to ensure safe and accurate landings. A 6-DOF lunar lander model is developed, considering mass variations and terrain-induced disturbances. A stable reference trajectory is defined, optimizing fuel consumption and landing precision. A Lyapunov-based adaptive law adjusts control gains dynamically to minimize tracking errors. Additionally, a Kalman filter estimates terrain slope and roughness during descent, enhancing the control system's response. The proposed method is validated through Monte Carlo simulations, comparing its performance against traditional PID and LQR controllers based on landing accuracy, fuel efficiency, and robustness to terrain variations. Results show that the MRAC framework improves landing accuracy by 50% over PID and reduces fuel consumption by 20% compared to LQR. Furthermore, it handles mass variations and terrain uncertainties without prior knowledge, making it suitable for autonomous lunar missions. The integration of terrain estimation ensures safe landings even in poorly mapped regions, addressing a critical challenge for future lunar exploration.