32nd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Interactive Presentations - 32nd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (IP)

LIDAR TECHNOLOGY APPLICATIONS IN SPACE

Abstract

Accurate navigation and terrain mapping are crucial for the success of space exploration missions, particularly for rovers, landers, and orbiters operating in challenging and often unknown environments. Digital Elevation Models (DEMs) serve as foundational 3D terrain datasets, yet the computational, memory, and energy constraints of spaceborne systems frequently hinder the real-time generation of high-resolution DEMs. These limitations reduce adaptability and accuracy, especially in dynamic terrains.

This work introduces a novel approach for real-time DEM refinement on hardware-constrained platforms, enhancing spatial accuracy and adaptability in unexplored or time-varying terrains. Our methodology consists of four key stages to achieve efficient DEM refinement while optimizing resource usage.

First, we analyze the computational and memory limitations inherent in spaceborne systems to establish feasible operational parameters within a Linear Time-Invariant (LTI) framework. Through quantization and pruning techniques, we optimize the DEM refinement process to strike a balance between precision and resource efficiency while developing a lightweight AI model.

Next, advanced memory reduction strategies—including model compression, edge computing, and optimized data handling—are employed to significantly improve processing speed. These techniques ensure optimal model performance within the strict capacity constraints of onboard systems. The refined model is then deployed on rover-like hardware to validate its real-time performance, scalability, and adaptability across diverse terrains, including dusty, rocky, and steep landscapes.

Our approach aims to develop autonomous and sustainable systems capable of real-time adaptation to complex extraterrestrial landscapes. By enhancing the capability of spaceborne systems to navigate safely and autonomously, our method substantially improves their ability to react dynamically to previously unobserved terrain features. Furthermore, the high-resolution DEM data generated through this method will directly benefit other mission objectives, such as identifying optimal landing sites, mapping areas of scientific and resource interest, and advancing planetary topography and geological studies.

The successful demonstration of AI-driven, hardware-efficient DEM refinement paves the way for more agile and resilient space missions. This scalable solution has broad implications for next-generation planetary exploration systems, extending from Mars and Moon missions to deep-space asteroid and comet exploration, and beyond. By integrating advanced AI and resource-efficient computing techniques, our approach represents a significant leap toward autonomous, high-precision exploration of our solar system's most challenging terrains.