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THE POTENTIAL OF DIGITAL TWIN TECHNOLOGIES FOR ENHANCED LUNAR OPERATIONS

Abstract

For decades, the space sector has relied on accurate, high-fidelity simulations to test spacecraft components, develop operational guidelines, and problem-solve failure scenarios. Digital twin technology takes simulation to a system-wide level across multiple environment parameters, excelling at modeling complex situations with various interdependencies.

Two factors contributed to the rapid rise of Digital Twin technology in the past decade: the development of cheap computing power at scale and the availability of large ground-truth datasets. Also known as machine learning and big data, these factors have reduced computing power needs for environmental simulations, allowing near-real-time simulations alongside direct sensor inputs at complex scenarios. With frequent applications in game engines, these streamlined solutions are increasingly expediting traditional testing schemes in the space sector.

The lunar environment presents a unique opportunity for Digital Twin technologies. On one side, the lack of atmosphere removes complexities from atmospheric drag, heat dissipation, and indirect illumination. Conversely, a crucial lack of high-fidelity datasets limits leveraging existing engines for lunar systems. Additionally, the irregularity of lunar gravity and Lagrangian mechanics in three-body systems require computing power at the linear level or above to simulate spacecraft operations.

The recent approach of creating synthetic datasets can overcome the limitations of insufficient datasets for engine development. These approaches utilize parallel simulations across multiple factors before combining factor outputs into a single environmental snapshot or model. Advanced algorithms using random forest aggregation or periodic factor combinations can still simulate complex outcomes from complicated inputs.

This study compares these challenges and opportunities of building and operating a Digital Twin for the lunar ecosystem and presents the potential market for such a solution. Digital Twin can provide highly efficient fleet or flock management solutions for networked systems on the moon, such as lunar satellite constellations, lunar surface rovers, or even base operations. Even for single-entity missions, Digital Twins can be a powerful tool as individual spacecraft operate with a growing number of sensors and communications environments.

The study concludes with a presentation on how Digital Twin technology can be applied to the lunar environment. As more sensors become networked and systems autonomous, Digital Twin allows us to scale the lunar ecosystem sustainably via space traffic management, resource utilization, and communications applications.