Multiphysics Modeling and Virtual Motion Simulation to Optimise Mining Systems in Extreme Conditions - Insights from Mars Science Laboratory (MSL) Curiosity Rover

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ABSTRACT

In the quest to access valuable critical minerals, humankind is expanding the frontier into extreme environments like space and deep-sea mining. These ambitious enterprises involve considerable costs and lengthy development cycles to ensure the robustness of mining systems in the face of the harshest conditions and unforeseen challenges. Unfortunately, obtaining information from these unexplored territories is complicated. Data is often scarce, incomplete or impossible to obtain until equipment is deployed, leaving engineers facing many uncertainties throughout the design, testing, production and preparation of such missions. Despite these challenges, these extreme environments operate under consistent physical and chemical principles that can be faithfully digitally replicated. However, unexplored areas and dynamic systems like weather and geology continue to carry uncertainties. While eliminating uncertainties remains elusive, Digital Twins offers a means of robust risk management tool. These virtual replicas can excel in simulating extreme conditions and unexpected events, helping optimise and validate mining system designs tailored for such hostile environments.

This study takes inspiration from the Mars Science Laboratory (MSL) Curiosity Rover's wheel damage rate to develop a Multiphysics Modeling and Virtual Motion Simulation (MMVMS) system. Using advanced Generative Design, this MMVMS system refines the MSL's design, simulates component and system performance, and assesses the risk of premature damage while operating on Mars. Additionally, MMVMS integrates cutting-edge CAD design technologies from aerospace and manufacturing to realistically recreate the Martian environment and a detailed representation of MSL, allowing mobility verification and validation simulation to test different components in terms of materials, design, weight, power and, therefore, cost. The research highlights the precision of MMVMS in replicating extreme conditions, simulating and evaluating internal and external variables influencing the entire system (rover) in real time, and predicting movements, failures, and premature damage. This sophisticated Digital Twin technology, showcased in this research, holds promise not only for space missions but also to be adapted for terrestrial and deep-sea mining operations.