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Dvirupa: A Dual-Mode Planetary Rover Integrating Autonomous Exploration and Crewed Mobility

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Abstract

Introduction: Extraterrestrial surface exploration faces severe logistical constraints; primarily high payload launches costs and operational downtime driven by crew fatigue. Traditional planetary exploration missions separate crewed mobility (such as lunar electric rovers) from unmanned robotic science platform creating redundant hardware mass and limiting operational bandwidth.Project Dvirupa addresses this inefficiency by introducing a dual-mode hybrid planetary exploration architecture. The rover combines a manual, two-seater crew transport capability with an autonomous science-gathering system capable of continuous, 24/7 operations. When astronauts require rest, the system transitions into an autonomous surveyor to conduct geological sampling and topographical mapping without human intervention.

The primary objectives of this study are:

- To evaluate payload and mass reduction achieved through dual-mode rover architecture.
- To model operational duty cycles comparing dual-mode vehicles against independent crewed/uncrewed setups.
- To demonstrate a control software framework for seamless mode transitions.

Methodology: System Architecture & Design: Developed a modular chassis CAD model featuring a 2-seater cockpit, drive-by-wire controls, and an integrated autonomous sensor suite (LiDAR, stereo cameras, and environmental sensors).Control & Telemetry Interface: Engineered a web-based rover telemetry and mission-control software architecture (dvirpa-rover-control-app) to manage remote navigation and mode toggling. Comparative Payload & Duty Cycle Analysis: Simulated mass budgets and operational uptime against single-purpose benchmarks (e.g., NASA's Lunar Electric Rover and standalone robotic rovers). Data Evaluation: Analyzed mission efficiency based on payload mass savings, power consumption per kilometer, and active operational hours per sol.

Results & Discussion: Payload Mass Efficiency: Consolidating crewed mobility and autonomous surveying into a single platform eliminates redundant chassis and powertrain mass, reducing launch payload requirements by an estimated 30–40% compared to dual-vehicle deployments.Continuous Operational Cycle (24/7): While single-purpose crewed rovers remain idle during crew sleep cycles, Dvirupa's autonomous operational profile increases science mission uptime from ~8 hours/sol to ~22+ hours/sol (accounting for maintenance and recharging).

System Integration: Control interface testing demonstrated stable telemetry exchange and safe autonomous fail-safes during simulated drive-to-autonomous state handoffs.

Conclusion: Project Dvirupa proves that dual-mode operational rovers provide a scalable, cost-effective blueprint for sustainable lunar and Martian exploration. Future developments will focus on:

- Integrating onboard sealed biological micro-chambers for in-situ life-science experimentation.
- Developing terrain-adaptive AI pathfinding algorithms for complex regolith navigation.
- Refining the physical scale prototype for full-spectrum obstacle traversal testing.

Keywords: Dual-Mode Planetary Rover; Autonomous Exploration; Crewed Mobility; Planetary Surface Navigation; Human-Robotic Collaboration; Space Exploration

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