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GRAVITY COMPENSATION SYSTEM FOR LUNAR ROVERS WITH POINT CLOUD TERRAIN-BASED HEIGHT PREDICTION

Abstract

As human lunar exploration advances, efficient rover design becomes crucial. However, the significant difference in gravitational environments between the Moon and Earth presents substantial challenges for lunar rover development. To address this discrepancy, researchers commonly employ suspension-based gravity compensation systems that provide upward tension to simulate lunar gravitational conditions. However, these systems encounter significant limitations when rovers traverse rough terrain. The primary challenge emerges from vertical height variations: when a rover ascends slopes, cables tend to slacken, resulting in insufficient upward force and inaccurate gravity simulation; conversely, during descents, cables become excessively taut, introducing unwanted resistance. This dynamic tension fluctuation damages experimental validity and rover performance assessment. Current gravity compensation systems prioritize horizontal suspension following or implement basic force feedback mechanisms for tension control. These systems lack the fast vertical axis response necessary for maintaining consistent tension during rapid height transitions. This deficiency is especially significant for microgravity experiments during rapid movement over rough terrain, where precise gravitational simulation directly impacts scientific data quality and operational performance evaluation.

To address these limitations, we designed a novel gravity compensation system consisting of four vertically arranged components: a suspension following mechanism, terrain scanning system, tension control system, and force sensor. The suspension following mechanism actively adjusts the overhead cable position to maintain consistent alignment with the rover as it moves. Our approach incorporated point cloud data of the experimental area to anticipate height variations along the rover's planned route. Specifically, the terrain scanning system mounted on the suspension following mechanism scanned the local terrain ahead of the rover. The rover's planned x-y trajectory was then projected onto this point cloud, generating a three-dimensional path with corresponding height sequences. By integrating height variation predictions into the control system and combining them with force sensor feedback, we achieved constant tension control on rough terrain.

Simulations demonstrated that our designed gravity compensation system significantly enhanced system response to vertical height changes compared to traditional methods, effectively reducing compensation force oscillation and error during rover movement on rough terrain. Verification at the Simulated Lunar Operations and Robotics Laboratory confirmed the system's significant advantages for gravity

compensation during rover movement across rough terrain. This innovation provided reliable support for ground-based lunar rover development and exploration, offering considerable scientific value and application potential.