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ILLUMINATION-ADAPTIVE DISTRIBUTED TASK PLANNING FOR ROBOTIC CLUSTERS IN LONG-TERM LUNAR BASE

Abstract

In the foreseeable future, humanity will establish large-scale bases on the lunar surface capable of supporting long-term scientific habitation. The construction of these bases involves massive engineering demands, extended timelines, and complex task sequences. Current single-unit lunar exploration vehicles cannot independently accomplish these challenges. Therefore, collaborative operations by multi-agent lunar exploration clusters are required. This necessitates collaborative operations by clusters of lunar exploration robots. Current lunar exploration systems worldwide predominantly rely on single rovers as primary units, which are inadequate for both comprehensive lunar exploration and future base construction. Consequently, the use of multi-vehicle clusters is emerging as a trend in lunar exploration systems, replacing traditional single-rover paradigms. Implementing such clusters involves addressing multifaceted challenges, including multi-agent task planning, cluster communication, and coordinated path planning. And this paper mainly focus on collaborative task planning. However, conventional allocation approaches prove insufficient for large-scale, long-term cluster engineering projects on the Moon, necessitating dynamic task planning algorithms with real-time environmental adaptability. This challenge is further compounded by the lunar surface's 14-day day-night illumination cycle—distinct from terrestrial conditions—which imposes critical solar energy constraints affecting rover operations, task allocation, and collaborative processes. To address these challenges, this paper proposes an illumination-adaptive distributed task planning algorithm that systematically integrates lunar lighting conditions into dynamic mission planning through a three-tier architecture: illumination-phase mission modeling establishing solar energy availability windows, energy-aware task allocation optimizing cluster capabilities during high-illumination periods, and dynamic priority adjustment algorithms redistributing workloads in low-light phases—collectively enhancing energy utilization efficiency by synchronizing high-energy tasks with peak solar availability and minimizing standby consumption through adaptive task phasing. By establishing a lunar illumination model and embedding it within the planning framework, the method enables real-time prioritization adjustments in response to changing lighting conditions. Comparing with existing algorithms, our approach exhibits two key advancements: 1) The heuristic-based framework decomposes long-term missions into phased short-cycle subtasks, enhancing operational efficiency while mitigating risks associated with prolonged operations through staged execution; 2) Incorporation of lunar-specific

illumination constraints optimizes energy utilization efficiency and reduces total mission duration for large-scale lunar projects. The proposed algorithm demonstrates operational effectiveness through three validated mechanisms: optimized energy utilization during illumination periods, adaptive task phasing aligned with lunar daylight cycles, and dynamic priority adjustments—collectively enhancing robustness in long-term mission planning under lighting constraints.