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HARNESSING EVOLUTIONARY ALGORITHMS FOR ADAPTIVE MODULAR ROBOTICS DESIGN IN LUNAR MISSIONS

Abstract

Modular robotics are frequently considered the best type of robotics system design for extreme environments due to their versatility and adaptability to unforeseen situations. The lunar environment is one of the harshest of such environments due to its lack of information, limited communication, extreme temperatures, significant radiation, and restricted resupply. Modular robotics in lunar terrain can cost-effectively explore the moon by enabling versatility in mission packages in small mass units across various circumstances.

However, on-site versatility requires significant pre-mission investment in systems design, hardware integration, and control algorithm development. Despite their theoretical effectiveness, the lack of modular robotics in extreme environments is partially due to the difficulties in designing a comprehensive algorithm to control robotic modules in such diverse and unforeseen environments.

This study focuses on how evolutionary algorithms, particularly genetic algorithms and reinforcement learning, can improve the performance of modular robotic systems that make modular robots feasible for lunar missions. Genetic algorithms use iterative selection processes to evolve robot morphologies and optimize control strategies. Reinforcement learning complements this approach to enable robots to refine their control policies during interaction with the environment, improving their ability to react to novel challenges. The two algorithms will, therefore, first enable the design of modular systems of limbs, joints, and actuators that maximize the operational flexibility of the robots and integrate different mission requirements into the fewest components. Second, the two algorithms will enable on-site adaptation learning that eliminates the need for significant dataset collection and training in favor of learning-through-execution methods.

The study aims to showcase how modern advances in genetic algorithms and reinforcement learning can combine in a hybrid optimization approach to enable a new generation of modular robotics. This integration will use genetic algorithms to generate optimal morphological designs and reinforcement learning to fine-tune real-time decision-making processes, reducing design complexity and improving robot control autonomy.

This study concludes that the hybrid optimization approach mentioned in the paper can open up pathways for modular robots to operate on the moon, where data and communication are limited, and rapid adaptation and modular switching are crucial for mission success. Furthermore, modular robotic platforms designed for rapid reconfiguration and testing have demonstrated the practical feasibility of these techniques in real-world applications.