IAF SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations - IAF SPACE EXPLORATION SYMPOSIUM (IP)

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SELF-LEARNING SPACECRAFT: REINFORCEMENT LEARNING FOR AUTONOMOUS SPACE EXPLORATION

Abstract

The future of space travel demands that spacecraft and planetary rovers make decisions independently in hostile environments with little human interaction. Although academic research into spaceship autonomy and machine learning is still on the rise, much more remains to be accomplished to implement contemporary machine learning techniques successfully within the realm of spaceflight challenges. Traditional rule-based control systems are challenged to act in unforeseen circumstances, thus necessitating a paradigm shift toward self-learning algorithms.

This paper addresses the implementation of reinforcement learning (RL) in space robotics to achieve online adaptation, threat evasion, and rational mission planning off the planet. Reinforcement learning may probably make us the most innovators in space exploration: that is, things like autonomously exploring some unknown celestial bodies, optimizing fuel usage, and intelligent trade-offs while planning missions by trade-offing risk or meanwhile reward. The future missions of RL would thus involve autonomous probes learning from possible past experience with the capability of adapting dynamically to changing extreme conditions and unforeseen obstructions, capabilities to perform long-term missions in deep space with reduced reliance on human operators and ground control, thereby increasing mission success chances.

As spacecraft adjust to novel and unpredictable space environments, we present a framework that uses RL-based rules to maximize trajectory planning, obstacle avoidance, and resource management. Through simulation-based training in deep-space and planetary environments, we show how RL agents may continually interact with their environment to learn optimum behaviors. Spacecraft may self-refine their operating tactics and become more resilient and efficient by using incentive systems that are in line with mission objectives. We also go over important issues including sample efficiency, safety limitations, and making decisions in real time when in space, where computing power is scarce. In order to overcome this, we use methods like curriculum learning, transfer learning, and model-based reinforcement learning to improve the autonomous control system's resilience and flexibility.

According to our investigations, RL-powered spacecraft have more flexibility than traditional techniques enabling real-time modifications in unknown regions. This sets the stage for the next generation of self-learning spacecraft capable of exploring deep space with minimum assistance from the ground, thus advancing AI-driven autonomy for space exploration.