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INTELLIGENT FUEL-OPTIMAL GUIDANCE STRATEGY FOR SMALL BODY FLEXIBLE LANDING

Abstract

The implementation of small body landing missions is faced with multiple challenges, including irregular gravitational fields, strong dynamic uncertainties, complex surface conditions and terrain obstacles. Affected by the environmental disturbance, control deviation and weak gravity, traditional rigid landers are likely to encounter with unexpected situations like bounce, rollover or even escape when touching down on the surface. In order to reduce the risk of landing, this paper proposes a design scheme of the lander that adopts a flexible structure. The envisioned flexible lander consists of multiple rigid body modules with thrusters and the flexible filler material connecting these modules. Since the flexible material performs well in absorbing collision energy, the bounce and rollover can be suppressed, thus improving the landing safety. Due to the effect of flexible connections between rigid modules, the dynamic system of the flexible lander is more complex, with stronger nonlinearity and coupling characteristics. Therefore, only simple analytical feedback methods like Apollo guidance and sliding surface guidance can be adopted as the landing guidance strategy. The methods based on optimal control is no longer applicable, which means the fuel consumption of the landing trajectories cannot be optimized, and the satisfaction of constraints such as thrust amplitude or obstacle avoidance cannot be considered. To solve the problem, this paper introduces reinforcement learning strategy into the analytical feedback guidance law. The reinforcement learning technique is especially suitable for parameter optimization of complex systems. It can be used for adaptive adjustment of the guidance parameters, enhancing the fuel efficiency and obstacle avoidance ability of the flexible lander.

To achieve the goals mentioned above, firstly, a simplified dynamic model of the flexible lander is built. The spring-damper-torsion spring system is employed to simulate the flexible connection characteristics among the rigid modules. On this basis, a closed-loop guidance law is designed using the terminal sliding surface method, which generates stable coordinated control commands for the multiple thrusters. Then the Markov decision process is constructed according to the dynamic model of the flexible lander. The guidance parameters of the terminal sliding surface strategy is adjusted through the reinforcement learning algorithm based on policy gradient theorem, obtaining trajectories with higher fuel efficiency and obstacle avoidance ability. The simulation result shows that the introduction of reinforcement learning mechanism can improve the control effect of terminal sliding surface strategy on complex dynamic systems, and further increase the safety and reliability of the small body landing process.