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A HIERARCHICAL TRAJECTORY PLANNING ALGORITHM FOR SPACE REDUNDANT MANIPULATOR CONSIDERING END-TASK CONSTRAINT

Abstract

The space station is exposed to the risk of space debris impact due to its operation in near-Earth orbit. Therefore, it is necessary to use the end hand-eye camera of the 7-degree-of-freedom manipulator of the space station to track and monitor the approaching space debris, resulting in the end-task constraint that must be considered when planning the trajectory for the manipulator. With this background, the fast motion planning problem of space redundant manipulator (SRM) with end-task constraint is studied in this paper by considering complex constraints such as kinematic constraint, dynamics constraint and obstacle avoidance constraint. Although both existing sampling-based and sequential convex optimization-based motion planning methods can achieve fast planning, the former scales poorly when complex constraints are considered, while the latter requires guessing the initial trajectory at startup. Therefore, this paper proposes a hierarchical planning algorithm that combines sampling method and sequential convex optimization method. The core idea is to first plan an initial collision-free joint trajectory for the SRM within the framework of the sampling method, and then use the sequential convex optimization method to plan an optimal joint trajectory for the SRM that satisfies the optimization index and multiple constraints. First, considering kinematic constraint and obstacle avoidance constraint, a trajectory planning algorithm based on Goal Biased Rapidly-exploring Random Tree (GB-RRT) and cubic spline curve is designed, and the collision-free initial trajectory is planned for SRM in joint space. Then, the optimal control problem model of SRM trajectory planning containing kinematic constraint, dynamics constraint, obstacle avoidance constraint and end-task constraint is established, and the convexification method of the model is proposed. For the obstacle avoidance constraint, it is treated as a linear inequality constraint of joint angular velocity based on the velocity damping method, and a continuous collision-free strategy in the discrete time region is designed. For the line-of-sight cone constraint of the end hand-eye camera, it is treated as a positive definite quadratic inequality constraint of the unit attitude quaternion. For kinematic and dynamics constraints, the second-order integrator and the convexification method of continuous linearization are adopted. Finally, the proposed hierarchical planning algorithm is numerically simulated. The results not only verify the effectiveness of the hierarchical planning algorithm proposed in this paper, but also show that it has the capability of fast planning under complex constraints.