An Anytime Trajectory Optimizer for Accurately Parking an Autonomous Vehicle in Tiny Spaces

Xiaoming Chen, Yueshuo Sun, Tantan Zhang, Xinwei Wang, Shengjian Xiong, and Kai Cao

***Abstract*—This paper proposes an anytime trajectory optimizer for accurately parking an autonomous vehicle in tiny spaces cluttered with obstacles. Existing methods suffer from limitations. For example, geometric-based methods generate paths rather than trajectories, mass point models failing in tiny berths, and full-dimensional models with large-scale constraints lead to long computation times. The proposed method addresses these shortcomings by formulating differentiable collision-avoidance constraints and pruning their scale using a trust region strategy. It employs an anytime framework to iteratively refine the solution, breaking previous constraints and establishing new ones. This feature enables the optimizer to converge to a new minimum, gradually improving the optimality of the trajectory. The collision-avoidance constraints are accurate, enabling operation in tight spaces, while the trust region strategy enhances computational efficiency. Extensive simulations confirm the proposed method's superiority over mainstream planners in cluttered environments and tiny parking slots, reducing average computation time by 90.19% compared to the baseline method while maintaining optimality.**

***Index Terms*—Trajectory planning, numerical optimal control, autonomous vehicle, unstructured environment, automated parking.**

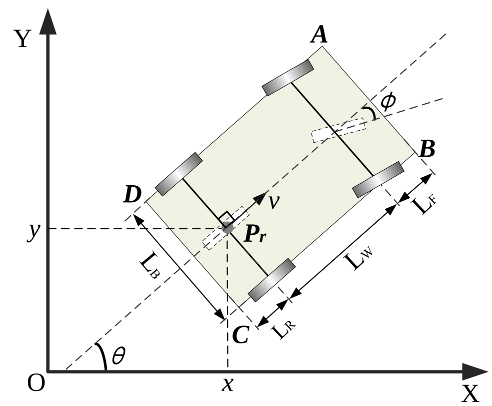

Fig. 1. Schematic of vehicle kinematics and geometrics.

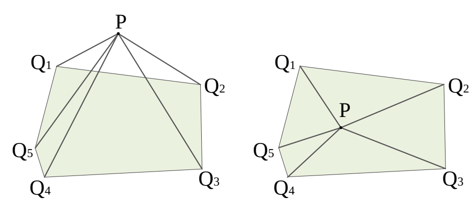

Fig. 2. Schematic of the triangle area criterion that judges whether point P is located within the convex polygon.

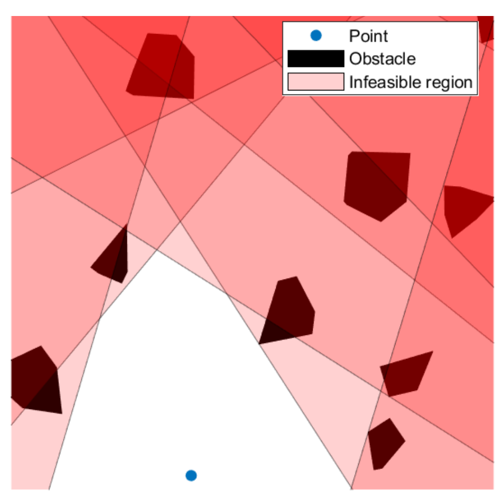

Fig. 3. Visualization of point P located outside obstacles in the differentiable obstacle-avoidance constraints formulation.

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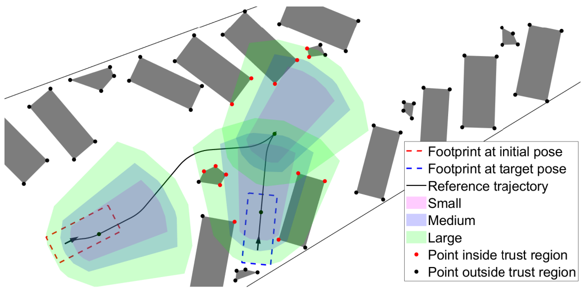


Fig. 4. Comparison of the coverage spaces of different trust region sizes.

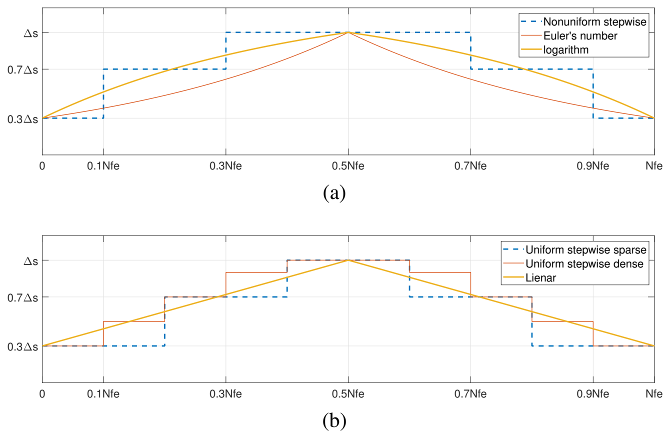


Fig. 5. Schematic of trust region sizes alterations. (a) Nonuniform growth. (b) Uniform growth.

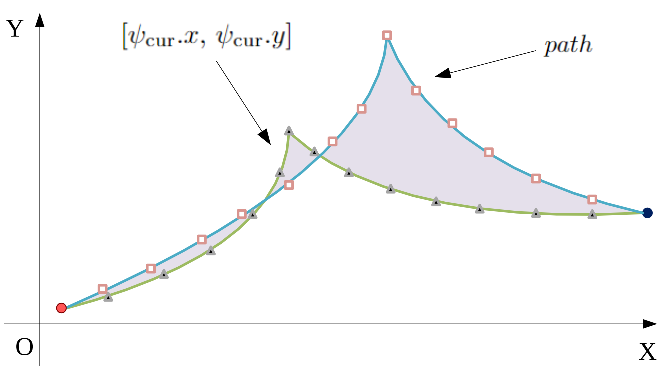


Fig. 6. Schematic of calculating the path gap.

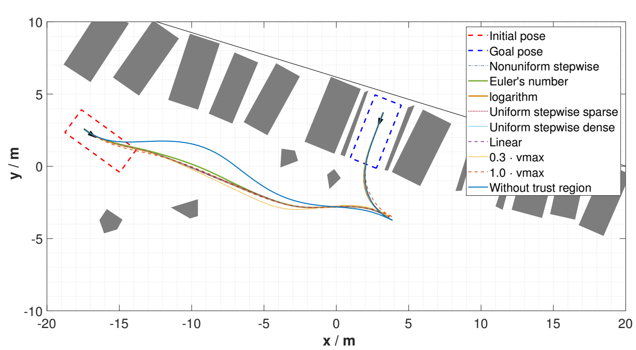


Fig. 7. Comparison trajectories optimized using nine strategies in Table ??.

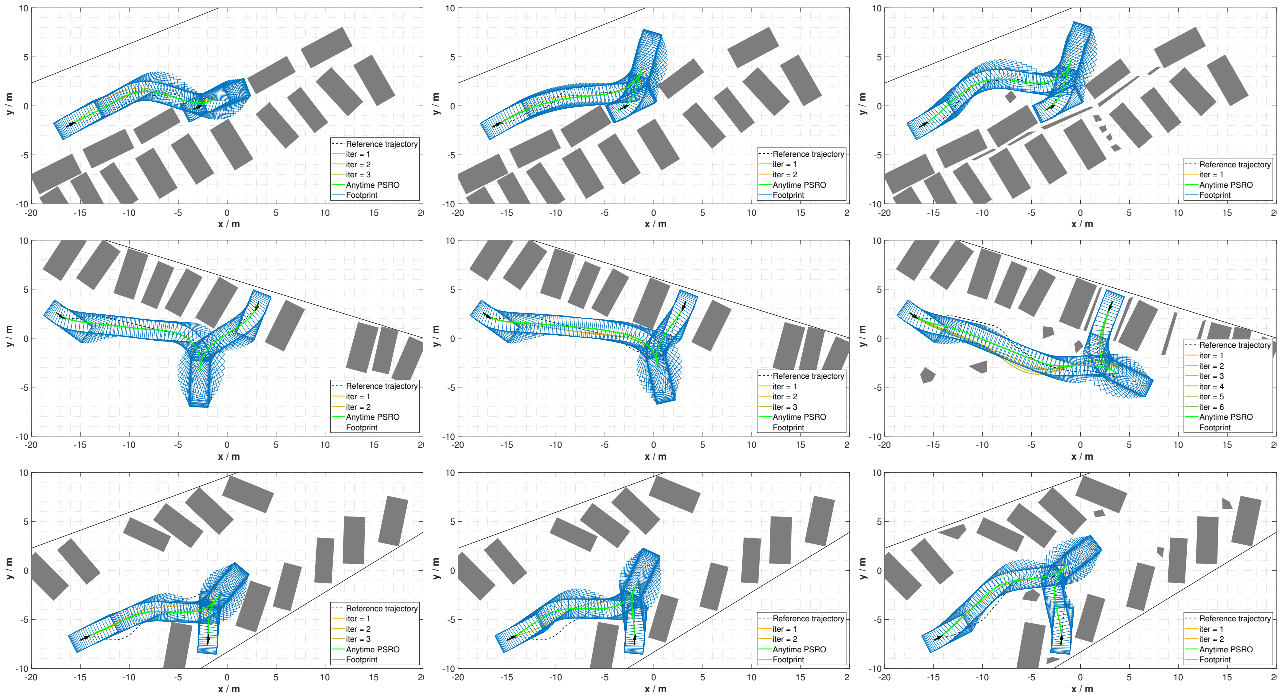
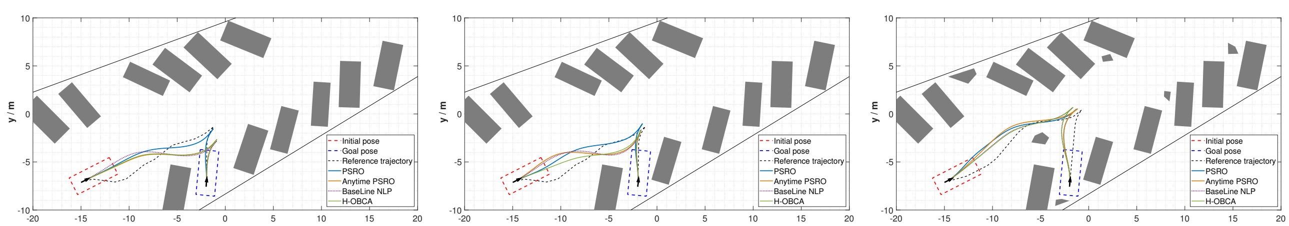


Fig. 8. Evolution of trajectories via Anytime PSRO in typical parking scenarios. Color changes from orange to green as the number of iterations increases.



(a) (b) (c)

Fig. 9. Comparison among trajectories optimized by four planners: (a) Case 7 - normal angular parking, (b) Case 8 - tiny parking slot, and (c) Case 9 - tiny parking slot cluttered with small obstacles.