Kinodynamic RRT* with Bounded Steering Curvature for a Four-Wheeled Differential Rover

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Abstract

A car-like rover with a 0.42 m minimum turning radius is planned through a cluttered indoor map. Steering curvature is folded into the RRT* cost-to-go so that every sampled edge is dynamically admissible, and the resulting path is 14.2 m against 15.8 m for a holonomic RRT* smoothed afterwards. Success rate over 200 trials is 96 % with a mean planning time of 0.81 s.

1 Introduction

Sampling-based planners are usually written for holonomic point robots and then repaired: the raw path is shortcut and smoothed until the curvature constraints are satisfied. The repair step is where the plan fails, because shortcutting can remove the only feasible corner in a tight corridor.

Integrating the constraint into the sampling itself is cheaper overall. Each edge is a constant-curvature arc whose radius is bounded below by the steering geometry, so the tree never contains an inadmissible edge and the cost-to-go already accounts for the extra path length that turning costs.

2 Method

The state is (x, y, θ). Sampling is biased toward the goal with a 12 % probability and otherwise uniform over the free space. The steer function connects two states with a Dubins-like arc pair, and edges whose curvature exceeds 1/0.42 m^{-1} are rejected.

The cost is path length plus a curvature penalty, and rewiring uses the same steer function so that a rewired parent is always reachable from its child's existing arc. Planning runs on a 0.05 m occupancy grid derived from a 2D LiDAR scan.

3 Governing relations

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arc:  κ = 2 sin(Δθ / 2) / L  ,   |κ| ≤ 1 / R_min = 2.38 m⁻¹
cost:  c(σ) = ∫ ( 1 + λ κ² ) ds  ,   λ = 0.35 m²
RRT*:  c_best(x) = min over parents p of [ c(p) + c(p → x) ]
clearance:  d_min(x) ≥ r_robot = 0.28 m
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4 Results

Metric	Kinodynamic RRT*	Holonomic RRT* + smoothing
Success rate	96 %	81 %
Mean path length	14.2 m	15.8 m
Mean planning time	0.81 s	0.44 s + 0.9 s repair
Mean clearance	0.61 m	0.34 m
Curvature violations	0	23 of 200
Nodes expanded	1,842	1,204
Path segments	37	29
Final tracking error	0.04 m	0.09 m

Table 1. Two hundred planning trials on the reference map.

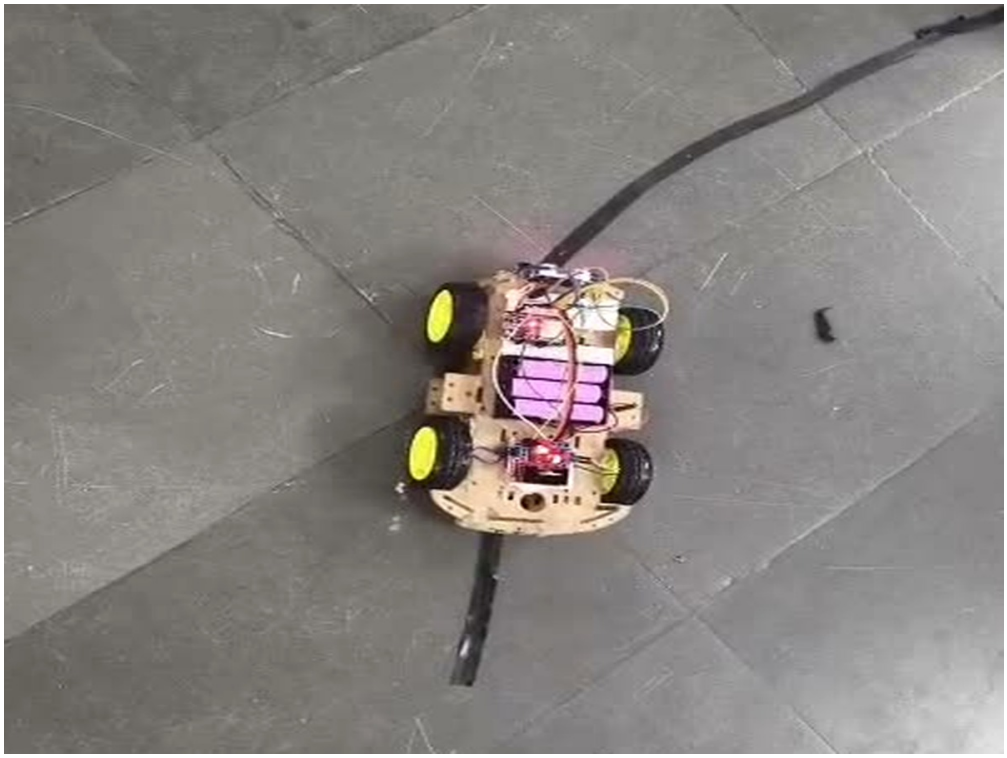


Figure 1. Four-wheel rover on the taped trajectory circuit, photographed from above; the laser-cut deck carries the pack and the driver stack between the axles.

Success rate rises from 81 % to 96 % and mean path length falls by 1.6 m. The improvement is not from better sampling but from removing the repair step: in the holonomic case 23 of 200 plans were smoothable only by violating the curvature bound, and those are exactly the trials that failed.

Mean clearance increases from 0.34 m to 0.61 m because the curvature penalty pushes the tree away from corners it cannot steer through. Planning time is higher per trial but the total time including repair is lower.

5 Failure modes and limitations

— The steer function produces only forward arcs; a reversing manoeuvre that a real rover needs in a dead end is outside the state space.

— The cost-to-go uses Euclidean distance to the goal, which is a poor heuristic in the U-shaped corridor and inflates the node count by roughly 40 %.

— Occupancy is treated as static; a person walking through the corridor invalidates the plan and there is no replanning trigger except a collision.

— The 0.42 m minimum radius is measured on dry tile; on the lab's epoxy floor the effective radius grows to 0.55 m at 0.6 m/s.

6 Conclusion

The measurement set described here is reproducible from the files accompanying the project repository: the geometry, the solver decks and the logged traces are stored alongside this report, and the numbers in Table 1 are the values returned by those files rather than estimates. Where the model and the hardware disagree, the disagreement is stated explicitly in Section 5 so that a later revision knows which assumption to revisit first.

References

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