

Navigation under Rank-Deficient Localization for Nonholonomic Ground Vehicle

-A Special Spiral Curve Method-

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Way-point-based geometric motion planning (MP) is an essential problem in robotics & autonomous driving applications. Traditional approaches usually combine different kinds of curves like circular arcs, clothoids, polynomials, Bezier curves, corresponding to a specific curvature function $\kappa(s)$ to realize open-loop steering. These methods predominantly rely on the assumption of complete displacement observability particularly precise localization to trigger curvature changes. However, industrial Automated Guided Vehicles (AGVs) utilizing magnet, visual guidance or 1D range sensor often operate under rank-deficient localization and MP methods for such sensor-limited system navigation are very limited. This work aims to fill this gap by proposing the application of special spiral curves featuring a linear relationship between curve curvature and 1-directional displacement. Experimental studies verified the feasibility and advantages of the proposed methods, compared with the traditional clothoid method.

The proposed method is intended to serve as a local steering primitive in a waypoint-based motion-planning framework. Therefore, the initial and target waypoints are assumed to be selected such that the local path can be contained in collision-free region F. Global waypoint generation and obstacle avoidance are outside the scope of this work and may be handled by a higher-level planner.

A local coordinate frame is attached to the initial configuration, with the x-axis aligned with the initial vehicle heading. In the rank-deficient localization condition considered in this paper, the lateral coordinate y can be measured accurately, whereas the longitudinal coordinate, or equivalently the traveled arc length, is not continuously observable with sufficient accuracy.

This information pattern appears, for example, in magnetic-guidance, visual-line-guidance, and one-dimensional range-sensing systems. In such systems, a conventional path represented by a prescribed curvature profile cannot be reliably executed because changes in curvature must be triggered according to an unavailable or inaccurate longitudinal position.

Definition. A lateral spiral curve (LSC) is the set of all points (x, y) starting from $(0, 0)$ in the plane that satisfy the following equation

$$\cos \theta = \frac{k}{2}y(y - 2d) + 1$$

With

$$k \geq 0, d \in \mathbb{R}$$

Through numerical integration, we depict the upper half, of the reachable set of the LSC in Fig. 1, which provides an overview of the reachable edge shape, determined by the fixed value of initial curvature. If we plan to design a smooth path that steers the car-like robot with maximal curvature constraint from the initial configuration to a desired one, it is natural to divide the path into two parts, namely, a lateral part and an orientation part. In this work, we present to compensate for the offsets by adjusting the lateral motion path, leading to the strategy as Fig. 2. This paper explores the application of LSC in path planning for car-like robots, which makes the navigation under rank-deficient localization possible.

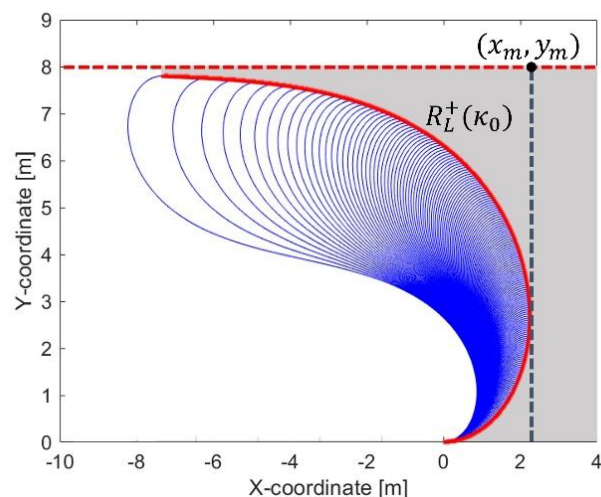


Fig. 1 Reachability set of LSC

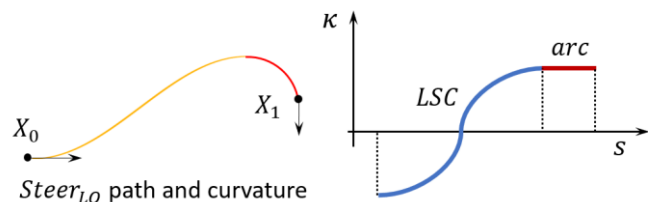


Fig. 2 Proposed path planning method