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Path Curvature Sensing Methods for a Car-like Robot

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Abstract. In this reserach we present path curvature sensing methods for a car-like robot, which can be applied to motion planning and motion control. Toward this goal, we use a steering wheel angle sensor and two encoders on the rear wheels in the robot. We then demonstrate two curvature sensing methods using a steering map and wheel odometry at the rear axle. Finally, experimental results are presented and discussed.

Keywords: Car-like robot, odometry, path curvature, steering angle.

1 Introduction

The subject of this research is path curvature sensing methods for a car-like robot. Path curvatures are typically used to generate desired robot trajectory paths in motion planning and motion control. Many researchers focused on controllers that could provide path convergence and stability [1-3]. Path curvature is generally an issue for mobile robots given steering restrictions determined by mechanical design and traction limitations [3]. Appreciable motion planning research has also considered physical constraints on velocity and path curvature to provide feasible references [4]. In particular, arcs or circles have popularly been applied to construct a path due to their simplicity and bounded curvature [5]. Thus, actual path curvatures should be measured to ensure the robot’s path following or tracking capabilities for given curvature limitations.

Whereas the focus of past research is curvature commands or reference path generation, we are interested in curvature sensing methods for a car-like robot in this research. In Method I, we use traditional wheel encoder-based odometry at the rear axle. In Method II, we propose a new steering map, which provides the curvature as a function of the wheel steering angle. Fig. 1 shows the autonomous robotic vehicle modified from a Dodge Grand Caravan. The vehicle is equipped with the Pronto4™ for autonomous control. We also installed an angle sensor on the steering wheel and quadrature encoders on the rear wheels to measure steering wheel orientation and wheel velocities. Steering wheel orientation and encoder signals can be used independently to estimate the path curvature of the vehicle. In experiment, we drive the autonomous vehicle for a short distance with a varying curvature to measure actual robot curvatures. Our main contribution is thus experimental validation of proposed sensing methods and the steering map method. Our sensing methods can be easily applied to a motion controller or planner.

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2 Curvature Sensing Methods

2.1. Method I: based on Odometry

Fig. 2 shows steering kinematics of a car-like robot. Applying the Cartesian coordinates, (x,y), and the heading angle, θ, kinematic equations for the robot are,

$$\dot{x} = v\cos\theta,\ \dot{y} = v\sin\theta,\ \dot{\theta} = v\frac{\tan\phi}{L}, \tag{1}$$

where v is the linear velocity at the rear axle center, C_1, ϕ is the steering angle, L is the distance between front and rear axles. Wheel odometry is based on quadrature encoders installed on the rear wheels. In this research the encoder resolution is 8 counts per revolution. These encoders provide wheel velocities. We can then easily find linear and angular velocities, v and $\dot{\theta}$, of the vehicle simply by averaging and subtracting wheel velocities given a tire circumference and axle length. Referring to Fig. 2, we can thus determine the curvature at the point C_1 by,

Fig. 1. Autonomous robotic vehicle.

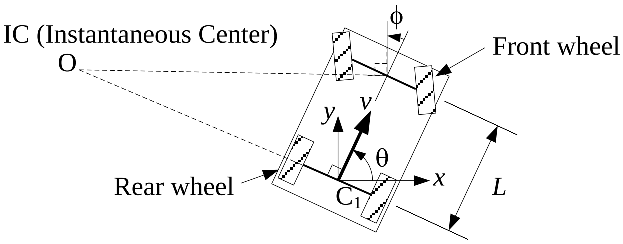

Fig. 2. Kinematics of a car-like robot.

$$\kappa = \frac{1}{\overline{OC_1}} = \frac{\dot{\theta}}{v} \quad , \tag{2}$$

2.2. Method II: based on a Steering Map

In the robot, the path curvature critically depends on the orientation of a steering wheel, which indicates that we can determine the path curvature of the robot by measuring the orientation of the steering wheel. Applying (2) to the third equations in (1), we have,

$$\kappa = \frac{\tan\phi}{L} . \tag{3}$$

Further, we need to model a steering mechanism to find the steering wheel rotation as a function of the heading angle. However, since the steering mechanism is complicated and nonlinear, its modeling is difficult. For simplicity, we experimentally evaluate the path curvature given a steering wheel orientation. As a result, we establish a steering map that describes a relation between steering wheel rotation and path curvature through experiments.

3 Experimental Results

We drive the vehicle forward for a short distance to obtain actual path curvature

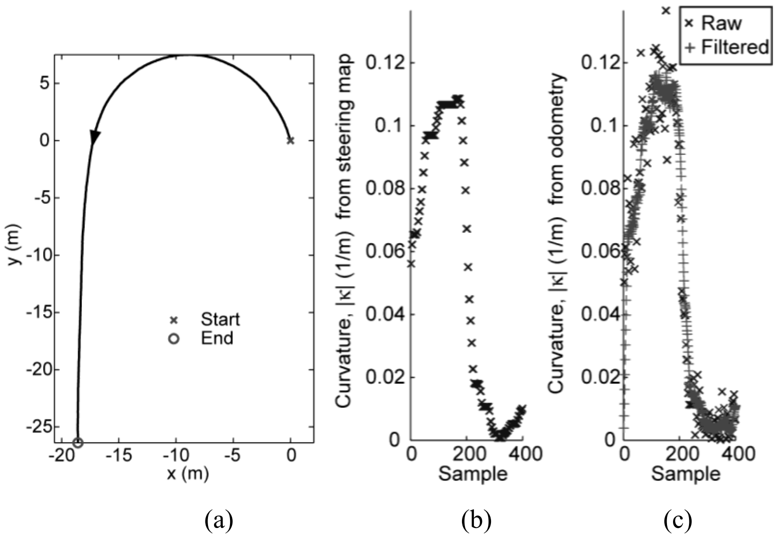

Fig. 3. Experimental results; (a) robot trajectory path, (b) curvature from the steering map, and (c) curvature from odometry.

data. Fig. 3 shows an actual trajectory path of the robot and experimentally measured curvatures applying steering map-based and odometry-based curvature sensing methods, respectively. Since raw odometry data is noisy, we also provide filtered curvature data applying a simple mean filter.

4 Conclusion

We experimentally measure path curvatures for a car-like robot applying two different curvature sensing methods based on odometry signals and steering map. Our approach is simple and requires inexpensive sensors. Our results show that the steering map may provide curvature data similar to the traditional odometry method obtained using relatively inexpensive sensors and a simple filter, which can be applied to a motion controller.

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