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An Improved Pure Pursuit Algorithm for Four-Wheel-Steering Autonomous Driving Vehicle

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Abstract: An improved pure pursuit path tracking algorithm is presented for a four-wheel steering (4WS) carrier vehicle to follow a desired path automatically. A bicycle vehicle model considering the 4WS carrier vehicle's structural and steering features is applied in the method. Real vehicle tests in an open large outdoor warehouse showed that the lateral tracking error was less than 0.56m at 20km/h. And we can conclude that the enhanced method for 4WS vehicle has good tracking ability on flat road.

Introduction

In the early study about path tracking method, researchers from Carnegie Mellon University (CMU) proposed a pure pursuit algorithm for front wheel steering unmanned vehicle [1]. It converted distance deviation to angle deviation which was the control output of the method. Subsequently, the algorithm was widely applied in unmanned ground vehicle, and could obtain high accuracy in mid-low speed condition [2-6]. However, there is no study about the application in control of 4WS vehicle. In this paper, in order to apply the pure pursuit algorithm in 4WS intelligent vehicle, a bicycle model considering of the 4WS vehicle's structural features and steering characteristics is applied in the method. And a modified pure pursuit path tracking method is proposed. Real vehicle tests were carried out on straight and curve lanes. The results showed that the lateral error was less than 0.56m while the vehicle's speed was 20km/h. Taking the low accuracy of the control system of the carrier vehicle into consideration, we can conclude that the proposed method is suitable for the 4WS unmanned ground vehicle.

Path Follow Method

Due to the time lag of vehicle and autonomous steering system, the dynamic response of vehicle lags behind control input. Therefore, preview control is necessary for autonomous vehicle to follow desired path [7], as a result overshoot can be avoided. We have verified the method on our autonomous vehicle in urban scenarios [4,5,6]. In this paper, a path following method for 4WS vehicle is proposed based on pure pursuit algorithm and 4WS characteristics of application platform.

Bicycle Model of 4WS Carrier Vehicle Assuming that tires are rigid and there is no slip at the wheels, the simplified bicycle model of 4WS vehicle [8] is showed in Fig. 1. Only the condition that front and rear wheels rotate reversely is considered in this model. L donates length of carrier vehicle; δ_f and δ_r donate deflection angles of front and rear tire respectively, R donates instantaneous steering radius of P, G is turning center of vehicle and line PG is perpendicular to heading of vehicle.

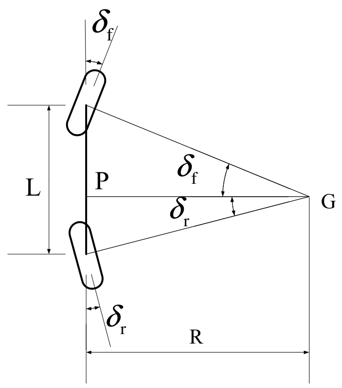


Fig. 1 Bicycle model of the 4WS vehicle

Here, R can be calculated by

$$R = \frac{1}{\tan\delta_f + \tan\delta_r} L \tag{1}$$

As our autonomous vehicle control law can guarantee that $\delta_r = \delta_f$, point P lies in the center of the vehicle. So Eq. 1 can be simplified as

$$R = \frac{L}{2}\cot\delta_f \tag{2}$$

Path Tracking Method for 4WS Carrier Vehicle As a 4WS vehicle, its steering kinematics and dynamics are different from that of a front wheel steering vehicle. So the path tracking method for 4WS carrier vehicle should be modified and improved.

Pure pursuit algorithm [1] is a geometrical method, which is generally used in front wheel steering control. It determines a circular arc along which the vehicle drives to the desired path from its current position. The arc is the desired trajectory of rear axle center of the front wheel steering vehicle. However, in order to apply the pure pursuit algorithm in 4WS vehicle, we assume the center of mass of the 4WS vehicle lies in the desired trajectory.

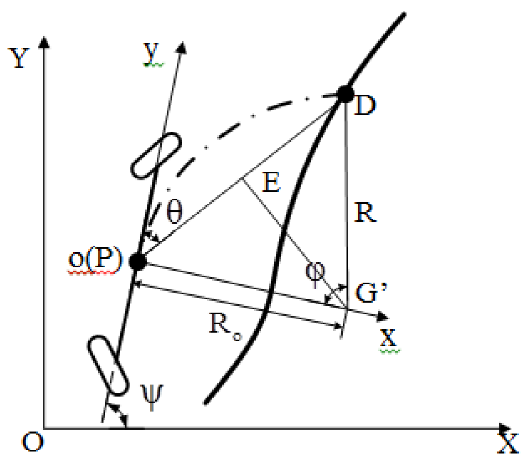


Fig. 2 Schematic diagram of path tracking algorithm for 4WS vehicle

Schematic diagram of path tracking algorithm for 4WS vehicle is shown in Fig. 2. In the world coordinate system (X-O-Y) and vehicle coordinate system (x-o-y), point o represents the mass center of the vehicle, assuming it lies in the center of carrier vehicle and coincides with point P; The thick solid line represents virtual digital path, which is generated by fitting curves from the desired GPS road points; Point D represents the preview point determined by the preview distance. (X_0,Y_0) is the coordinate of o in word coordinate system, (oD) is the coordinate of D in word coordinate system, and (x_d,y_d) is the coordinate of D in vehicle coordinate system; ψ is the angle between vehicle heading and positive direction of X axle; R_o is the instantaneous steering radius of o; G' is the center of arc oD; φ is the angle between the vehicle heading and tangent direction of arc oD in point D; θ is angle of vehicle heading change from o to D, and $\varphi=2\theta$.

Transform the coordinate of preview point D in word coordinate system to vehicle coordinate system by

$$\begin{cases} x_d = (X_d - X_o)\sin\left(\psi - \arctan\dfrac{Y_d\text{-}Y_o}{X_d\text{-}X_o}\right) \\ y_d = (Y_d - Y_o)\cos\left(\psi - \arctan\dfrac{Y_d\text{-}Y_o}{X_d\text{-}X_o}\right) \end{cases} \tag{3}$$

And R_o can be calculated by

$$R_o = \frac{\sqrt{y_d^2 + x_d^2}}{2\sin(\arctan\dfrac{y_d}{x_d})} \tag{4}$$

Combining with carrier vehicle model Eq. 2, meanwhile R_o=R, desired wheel angle can be gained:

$$\delta_f = \delta_r = \arctan\frac{L\sin(\arctan\dfrac{y_d}{x_d})}{\sqrt{y_d{}^2 + x_d{}^2}} \tag{5}$$

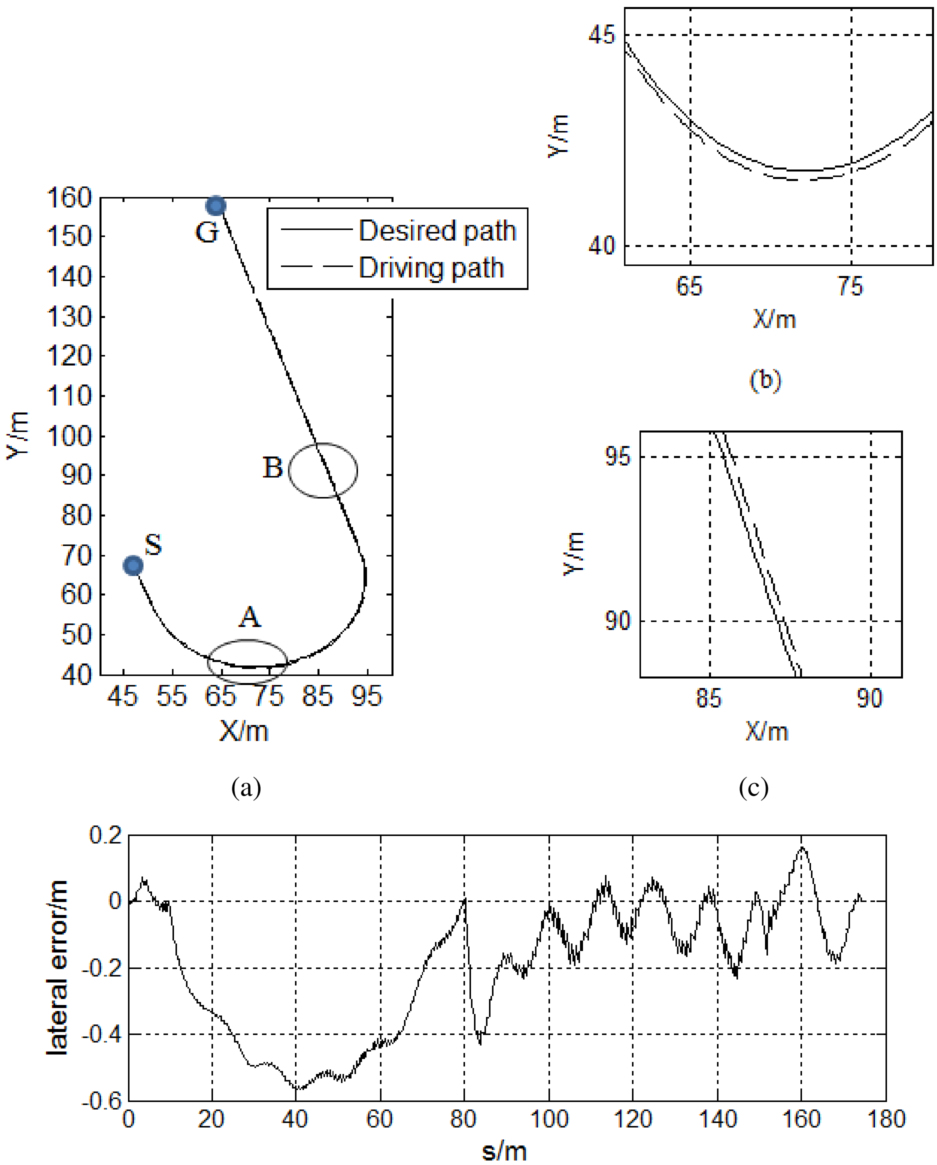
where L denotes the length of carrier vehicle, and x_d and y_d can be obtained from Eq. 3.

Low level controller calculates actuator control output based on the desired wheel angle obtained by Eq. 5, as a result, the deviation between real and desired path can be consequently eliminated.

Experiments on ADV

In order to testify the validity and feasibility of the modified path tracking method, experiments are carried out on our self-developed autonomous driving vehicle (ADV). The length and width of the vehicle are 8.8m and 2.9m respectively. The four wheels are steered by four hydraulic servo cylinders respectively. Front wheels and rear wheels turn in opposite direction in order to decrease steering radius of the large vehicle. Its direction and speed are controlled by low level controller.

Fig. 3 shows one of the experimental results, which consists of straight lane tracking segment and 180 degrees U-shape turn lane tracking segment. In this test the maximum speed of ADV is 20km/h in straight lane and 5km/h in curve lane. In Fig. 3 (a), the solid line represents the desired road path and the dotted line represents the actual measured path of ADV. Change of lateral error is presented in Fig. 3 (b). On straight lane segment the tracking error is less than 0.2m, and on 180° U-shape turn the tracking error is less than 0.56m.



(d)

a) Comparison between desired path and real driving path b) Partial view of A

c) Partial view of B d) The change of lateral error

Fig. 3 Experiment results of path tracking

Due to the deviation of sensors and actuators and response lag of vehicle system, the desired steering wheel angle cannot be achieved precisely and quickly. In the straight segment, there is a little shake. And when ADV tracks the 180 degree U-shape turn lane the lateral error is quite large. However, the width of automotive vehicle lane is 3.5 meters referring to “Technical Standard of Highway”[9], and the width of ADV is 2.13 meters. So the lateral error less than 0.56 meters meets the application requirement.

Conclusion

Aiming at 4WS carrier vehicle running in known routes, a path tracking method is presented in this paper. We proposed an enhanced pure pursuit algorithm which is suitable to four-wheel-steering vehicle. The real vehicle test results showed that the lateral tracking error was less than 0.56m at 20km/h. Because the vehicle is relatively larger, the deviation of sensors and actuators, and the response lag of vehicle system are much bigger than smaller and ordinary vehicles, the tracking accuracy is acceptable.

For our future work, we will continue to build the running digital paths for carrier vehicle in outdoor warehouse or port. And this work will be based on our previous work, a hybrid map-based navigation method for unmanned ground vehicle [10].

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