Adaptive Pure Pursuit Model for Autonomous Vehicle Path Tracking

Lingshang Kong

[1]School of Automation, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

valaxkong@163.com

Abstract

Pure-Pursuit(P-P) model is widely used in the path tracking for unmanned vehicles because of its simple, practical, efficient and intuitive. But it has poor adaptability to the change of vehicle speed. Because the controller parameter (forward-looking distance) is constant, the ordinary P-P model can only achieve a good path tracking in a certain speed. When the vehicle speed exceeds the limit range, there will be a large tracking error. In this paper, the linear stability of P-P model is analyzed, then the adaptive forward-looking distance decision strategy is proposed. The improved P-P model is called adaptive P-P model. Adaptive P-P model can be used to track the path with low error at any speed

Keywords

Autonomous vehicle, Path Tracking, Adaptive, Pure Pursuit Model.

1. Introduction

The purpose of intelligent vehicle trajectory tracking control is to design the controller, which makes the lateral error and azimuth error of vehicle and reference path tend to zero. Intelligent vehicle is a typical nonlinear, time-varying, strong coupling and underactuated characteristics, how to design the controller to realize the local path of high precision, stability, comfort and tracking is a key problem of intelligent vehicle path tracking research. Pure-Pursuit Tracking Model(P-P Model)model is the earliest and most widely used model in intelligent vehicle motion control. In engineering applications, from the open material, this "Stanley", "Sandstorm"(Standord DARPA Team)[1],"Talos"(MIT DARPA Team)[2],"KuaFU"(BIT FC Team)[3,4] and other intelligent vehicles using the path tracking method has achieved good results in various competitions and tests.

In order to improve the control precision of the pure pursuit model, the influence of the preview distance on the stability of the model P-P is analyzed in this paper. In the stability range, an adaptive preview distance strategy is designed, which can track the reference path successfully at any speed. Simulation results show that the proposed method is more effective than the P-P model with fixed preview distance, and has lower path tracking error.

2. Adaptive Pure-Pursuit Tracking Model

2.1 Pure-Pursuit Tracking Model

Pure-Pursuit is based on the famous "bicycle model". Based on the Ackerman assumption[5], the vehicle kinematics equation is obtained:

$$\begin{cases} \dot{x} = v \cdot \cos\theta \\ \dot{y} = v \cdot \sin\theta \\ \dot{\theta} = v \cdot \tan\delta / L \end{cases} \tag{1}$$

where, (x, y, θ) respectively, indicate the coordinates and heading angles of the anchor points of the vehicle. v is the forward speed, δ is the steer angle, L is the vehicle wheelbase.

The schematic of the model is shown in Fig.1

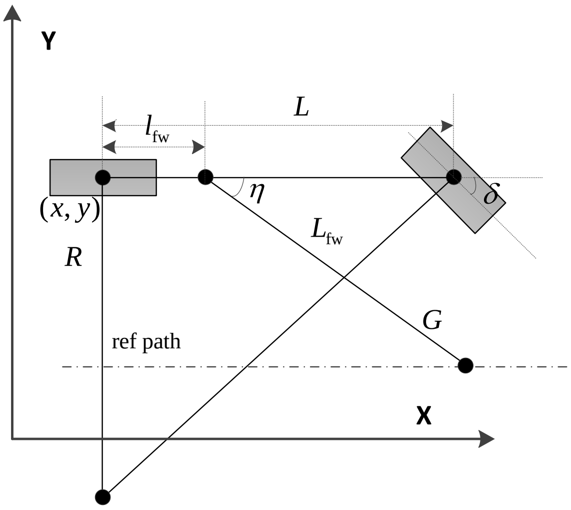

Fig. 1 Schematic of Pure-Pursuit Model

here, "ref path" is the piecewise linear reference path, R is the radius of curvature, l_{fw} means the distance between anchor point to rear axle, L_{fw} is forward-looking distance, η is the heading of the look-ahead point from the forward anchor point with respect to the vehicle heading, G is current goal point. The Pure-Pursuit control law is:

$$\delta = -\tan^{-1}\left(\frac{L\sin\eta}{\frac{L_{fw}}{2} + l_{fw}\cos\eta}\right) \tag{2}$$

2.2 Stability analysis

Therefore, it is necessary to analyze the stability of P-P model before putting forward adaptive strategy.

The steering mechanism is modeled as a first-order system considering the mechanical limitations of the steering mechanism.

$$\dot{\delta} = \frac{1}{\tau}(-\delta + \delta_c) \tag{3}$$

where δ_c is current steer command, τ is steering time constanct. For forward drive, δ_c follow control law as Eqs.(2). From the geometry, the following relation holds

$$\eta = \theta + \sin^{-1}\left(\frac{y + l_{fw}\sin\theta}{L_{fw}}\right) \tag{4}$$

Linearizing the closed-loop system Eqs.(1)-(4).Define the state $z = [y\ \theta\ \delta]^T$,we have the closed-loop linear dynamic as

$$\dot{z} = Az, \text{where } A = \begin{bmatrix} 0 & v & 0 \\ 0 & 0 & v/L \\ -L/\tau L_{fw}\left(\frac{L_{fw}}{2} + l_{fw}\right) & -L(L_{fw} + l_{fw})/\tau L_{fw}\left(\frac{L_{fw}}{2} + l_{fw}\right) & -1/\tau \end{bmatrix} \tag{5}$$

The characteristic equation of Matrix A can be written as

$$s^3+\frac{1}{\tau}s^2+\frac{v(L_{\text{fw}}+l_{\text{fw}})}{\tau L_{\text{fw}}(\frac{L_{\text{fw}}}{2}+l_{\text{fw}})}s+\frac{v^2}{\tau L_{\text{fw}}(\frac{L_{\text{fw}}}{2}+l_{\text{fw}})}=0 \tag{6}$$

Using Routh criterion ,the system Eq.(5) will be stable when

$$\frac{1}{\tau}>0 \tag{7}$$

$$\frac{v(L_{\text{fw}}+l_{\text{fw}})}{\tau L_{\text{fw}}(\frac{L_{\text{fw}}}{2}+l_{\text{fw}})}>0 \tag{8}$$

$$\frac{v^2}{\tau L_{\text{fw}}(\frac{L_{\text{fw}}}{2}+l_{\text{fw}})}>0 \tag{9}$$

Eqs.(7) and (9) are naturally satisied since $\tau>0, L_{\text{fw}}>0, l_{\text{fw}}>0$.When $v>0$,namely forward drive, system stability condition can be obtained:

$$L_{\text{fw}}>v\tau-l_{\text{fw}} \tag{10}$$

2.3 Adaptive forward-looking distance strategy

The forward-looking distance is the only parameter of the Pure-Pursuit model, which determines the quality and stability of the Pure-Pursuit model. Considering Eqs.(10), l_{fw} and τ are constant. L_{fw} should be adaptive to vehicle speed v. Therefore, this paper designs the following adaptive rules for L_{fw}:

$$L_{\text{fw}}=\begin{cases}L_{\min}, & |v|<|v|_{\text{change}}\\ K_{la}|v|, & |v|<|v|_{\text{change}}\end{cases} \tag{11}$$

where, $L_{\min}$ 、 $|v|_{\text{change}}$ 、 K_{la} are constant, $|v|$ is the absolute value of the current vehicle speed, $L_{\min}$ is the minimum steering radius of the vehicle, $K_{la}\cdot|v|$ indicates the forward-looking distance when vehicle runs at a high speed. K_{la} is an adjustable parameter, called gain of forward-looing gain. According to the previous analysis, with the increase of speed, the gain should be reduced. This can ensure the stability of the system at the same time, improve the dynamic performance of the tracker, to prevent excessive correction. According to a lot of experiment, suggests $K_{la}=2.25$. According to the relation $|v|_{\text{change}}=\frac{L_{\min}}{K_{la}}$, $|v|_{\text{change}}$ should be 2.22.

3. Simulation

In order to prove the effectiveness of the adaptive strategy proposed in this paper, the path tracking simulation experiment is carried out. The red piecewise linear line in the picture is the path to be tracked, named reference path. Under two different vehicle speeds, the ordinary P-P model and adaptive P-P model are used to simulate. Parameters of vehicle are: $L=2.1$, $|\delta_{\max}|=0.5435$, $|\dot{\delta}_{\max}|=0.3294$. Forward looking distance applied in traditional P-P model is $L_{\text{fw}}=3$. In the adaptive P-P model, forward looking distance is adaptive as Eqs.(11).

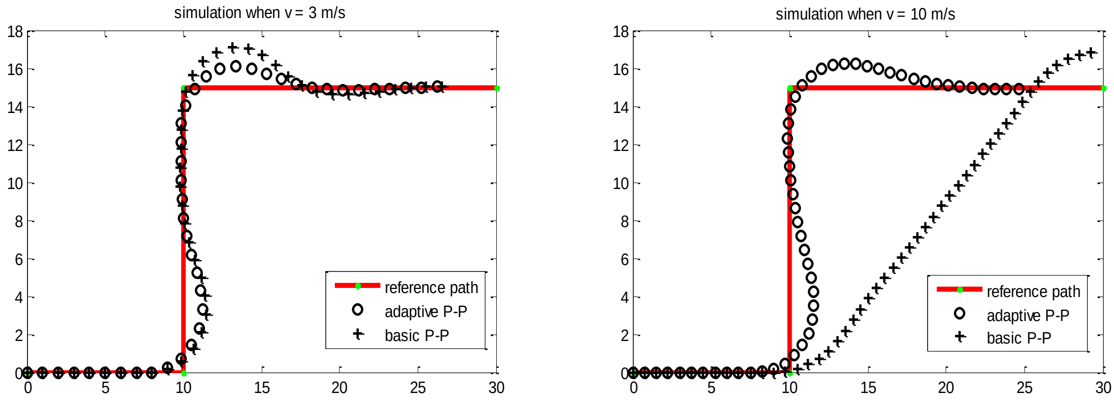

Fig. 2 Simulation at two speed

When the vehicle speed is 3m/s, the tracking error of the original P-P model and adaptive P-P model is similar. When the vehicle speed is 10m/s, the original P-P model has a larger tracking error. The adaptive P-P model shows the adaptability to the change of vehicle speed, and still has a small path tracking error

4. Conclusion

In this paper, the linear stability of P-P model is analyzed. Based on the stability conditions, an adaptive strategy of forward looking distance is given. In this paper, an adaptive P-P model can be used to adjust the forward looking distance according to the change of vehicle speed. From the simulation results, compared with the original P-P model, the adaptive model can keep the stability of path tracking and reduce the tracking error.

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