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Design and Implementation of Fast Terminal Sliding Mode Control for Vehicle Lane Keeping by Using Virtual Prototyping Simulations

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ABSTRACT: This article presents a new method to improve lane tracking performance and to create automatically lane keeping system for active front steering (AFS) vehicles. To achieve full tracking and stabilizing the lateral position of the vehicle, a new approach based on the fast terminal sliding mode control (FTSMC) is utilized which is responsible for reducing the rate of convergence and getting finite-time tracking control. Moreover, it is shown that the proposed controller is robust against vehicle mass uncertainties and external disturbances. The results obtained from co-simulation of ADAMS CAR and MATLAB show the controller efficiency to track the desired path and to guarantee the yaw stability under uncertain conditions.

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1- Introduction

Automatic lane keeping systems are active steering control units which are designed based on linear or nonlinear control methods. With increasing the vehicle speed, fast and robust performance of the controller against uncertainties and external disturbances could be seen as critical performance measures. Because of their robustness against uncertainties and external disturbances, sliding mode controllers have received a large attention in recent years.

In this paper, to model the dynamic behavior of the vehicle, a linear bicycle model is considered.The main purpose of the present research is to design a controller based on fast terminal sliding mode control, a modification of traditional sliding mode controller, which, in addition to the robustness property of sliding mode controller, benefits from a high speed response regardless of the initial start point. Our control method is designed for a front wheel steering (AFS) vehicle.

2- Vehicle Modeling

To show the vehicle lateral dynamics, a bicycle model of vehicle is used. The describing equations of this model is as follows:

$$\begin{bmatrix}\ddot{y}\\ \ddot{\psi}\end{bmatrix} = \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\dot{y}\\ \dot{\psi}\end{bmatrix} + \begin{bmatrix}b_{11}\\ b_{21}\end{bmatrix}\delta_f \quad (1)$$

$$a_{11} = -\frac{(c_f + c_r)}{mv_x} \qquad a_{12} = \frac{(l_r c_r - l_f c_f)}{mv_x} - v_x$$

$$a_{21} = \frac{l_r c_r - l_f c_f}{I_z v_x} \qquad a_{22} = -\frac{(l_f{}^2 c_f - l_r{}^2 c_r)}{I_z v_x}$$

$$b_{11} = \frac{c_f}{m} \qquad b_{21} = \frac{l_f c_f}{I_z}$$

Where, C_f is the cornering stiffness of front tire, C_r the cornering stiffness of rear tire, I_z the yaw moment of gravity center, l_f the distance between front wheels, l_r the distance between rear wheels, m the vehicle mass, y the lateral position, ψ the yaw rate and v_x is the longitudinal speed of vehicle.

3- Control Law

According to the excessive use of sliding mode controllers, to improve its performance, terminal sliding mode controllers (TSMC) have been developed in the recent years [1]. The focus of terminal sliding mode control is on reducing the convergence rate by considering a nonlinear surface instead of the conventional linear surface in SMC. Although the main advantage of TSMC is to decrease the convergence time compared with conventional SMC, it reduces the convergence rate when system states are far away from the equilibrium point. To overcome this problem, Fast Terminal Sliding Mode (FTSM) surface with extra linear term is recommended. In the following, we design a FTSMC for system with Equation (1). It is assumed that the reference yaw angle is achieved from the method mentioned in Marino et al. study [2]. Consider the sliding surface as bellows:

$$S = \dot{e} + \alpha e + \lambda e^{\frac{q}{p}} \quad (2)$$

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α, λ, q, p : Constant values

Where

$$e = \psi - \psi_{des} \tag{3}$$

The main control input is achieved by the following sum:

$$\boldsymbol{\delta} = \boldsymbol{\delta}_{eq} + \boldsymbol{\delta}_{reach} \tag{4}$$

According to the reaching condition

$$S\dot{S} < -\eta|S| \tag{5}$$

η : Constant value

The reaching term would be chosen as:

$$\boldsymbol{\delta}_{reach} = Ksign(S) \tag{6}$$

K : Constant value

To obtain u_{eq}, the condition $\dot{S}=0$ should be established. Therefore, we have

$$\dot{S} = \ddot{e} + \alpha\dot{e} + \lambda\dot{e}e^{(q/p)-1} \tag{7}$$

Finally

$$\delta_{eq} = \frac{1}{\hat{b}_{21}}\left(-\hat{a}_{21}\dot{y} - \hat{a}_{22}\dot{\psi} + \ddot{\psi}_{des} - \alpha\dot{e} - \lambda\dot{e}e^{\left(\frac{q}{p}\right)-1}\right) \tag{8}$$

For improving the performance of controller and its implementation removing chattering is essential. One of the common methods for improving the switching operation and consequently, eliminating the undesirable effects of chattering, is to set a boundary layer around the switching surface [6]. In practice, for doing this, function sign(s) is replaced with function sat(s/φ) in which *sat* is the saturation function and φ is the thickness of the boundary layer which could be adjusted to reduce the chattering.

4- Simulation Results

In this paper, to test the performance of the proposed controller, we implement the method via numerical simulations by co-simulation of MATLAB/Simulink and ADAMS CAR software. At first, a nonlinear model of the vehicle is constructed in ADAMS environment. Then, the new fast terminal sliding mode controller is designed based on parameters in Table 1 and is tuned appropriately. Finally, this controller is implemented on ADAMS model by co-simulation of MATLAB Simulink and ADAMS CAR software. In the first phase of test, longitudinal velocity is assumed to be constant and equal to 80km/h, and the frictional coefficient between the road and tires is 0.9.

According to Figure 1, it is seen that using FTSMC, the vehicle with high accuracy tracks the maneuver path.

In the next step, for checking the robustness of the proposed controller, uncertainty in the mass of vehicle and changes in the coefficient of friction to 0.4, which is the disturbance input in the previous speed (80km/h) is taken into account.

Table 1. Parameters of vehicle

Parameter	Value	Unit
m	1335	Kg
I_z	3782	Kgm^2
C_f	190000	N/rad
C_r	190000	N/rad
l_f	1.106	m
l_r	1.454	m

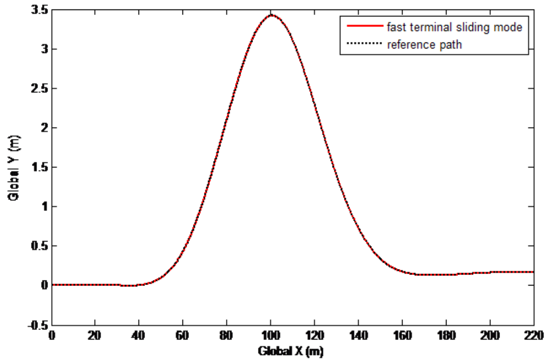

Figure 1. Lateral position in double lane change maneuver

Figure 2 show the results of the test.

As seen in Figure 2 in presence of the disturbances the vehicle has been able to track the reference path by using a fast terminal sliding mode controller.

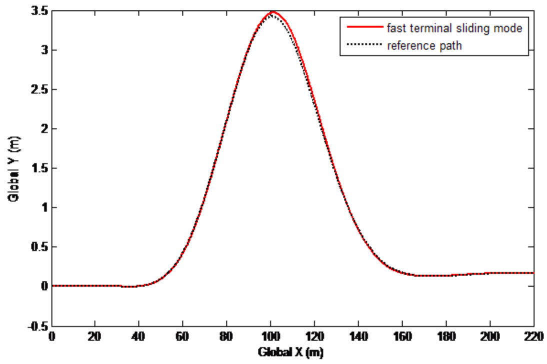

Figure 2. Lateral position in double lane change maneuver under road disturbance and mass uncertainty

5- Conclusions

In this study a controller based on fast terminal sliding mode control for improving performance of path tracking and yaw stability for AFS vehicle was presented. This controller was implemented on ADAMS model by co-simulation of MATLAB Simulink and ADAMS CAR software. Simulation results show the ability of the proposed controller in improving the performance of path tracking and desired yaw rate under disturbance conditions.

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