Control of Vehicle’s Mixed Longitudinal and Lateral Stability with Engine Dynamics Using Super Twisting Control Algorithm

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ABSTRACT

Vehicle stability control is one of the most important subjects in control engineering field. Many research activities have been done to develop more comfort and safe travel for passengers. In this paper, vehicle mixed stability in longitudinal and lateral motion has been investigated. Four wheel seven degrees of freedom model of vehicle is considered to extract the dynamic equations and closed loop system simulation. Dugoff’s nonlinear model has been used to simulate the behavior of tyres and road, and Cho’s engine model with two state variables has been used for vehicle power system simulation, so it makes the input torque to wheels to be more realistic. Because of the good robustness properties of sliding mode control, the second order sliding mode with super-twisting algorithm has been used for calculation of control inputs. This method is proved to be so appropriate and useful in the case of uncertainty in complicated vehicle dynamic model and multiple disturbances in vehicle motion. Engine throttle angle and yaw moment have been considered as longitudinal system and lateral system control inputs respectively. Longitudinal slip coefficient and yaw rate are considered as system output. Simulation results shows the effectiveness of the proposed method.

KEYWORDS


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1. Introduction

One of the major aspects of vehicle dynamics is the stability of motion which is divided into two main problems, the stability of longitudinal and lateral motion. Traction/ABS control system is used for longitudinal stability in accelerating/decelerating maneuvers [1, 2]. Lee and Tomizuka [2] used adaptive sliding mode and adaptive fuzzy logic control methods to vehicle traction force stability and control in order to achieve fastest acceleration/deceleration and compared the results of the two methods. Kabganian and Kazemi [3] applied the first order sliding mode to control the traction force of the vehicle. They involved the engine dynamics into dynamic equations and, using two sliding surfaces, designed tracking controller to compute the engine throttle angle based on the desired slip ratio.

Two major methods are proposed for lateral stability control, Active Front Steering method (AFS) which is based on the modification of steering input of driver, and Yaw Moment control which is by introducing turning yaw moment to vehicle dynamics to control its lateral stability [4, 5]. Canal et al. [4] used internal model control method to improve vehicle yaw rate dynamics and Liaw and Chung [5] applied feedback linearization technique for vehicle lateral stability. Zhao et al. [6] designed modular integrated longitudinal, lateral, and vertical vehicle stability control for distributed electric vehicles.

In this paper, vehicle mixed stability in longitudinal and lateral motion has been investigated considering engine dynamics. Four wheel seven degrees of freedom model of vehicle [7] is considered to extract the dynamic equations. Dugoff’s nonlinear model has been used to simulate the behavior of tyre and road, and Cho’s [8] engine model has been used for vehicle power system simulation. Two separate control systems are provided to maintain the vehicle’s longitudinal and lateral stability, each designed with a second order sliding mode using super-twisting algorithm [9]. The throttle angle is computed by using one sliding surface resulting to reduction in computational cost of the controller.

2. Problem Formulation

Differential equations governing vehicle and engine dynamics are given through equations (1) to (8) including seven degrees of freedom for vehicle dynamics [7] and two degrees of freedom concerning engine dynamics [8]. The vehicle is considered front wheel steer and drive through differential gear. The kinematic coupling between engine and front wheels imposes kinematic constraint between front wheels speeds and engine speed, which eliminates one of state equations. The remaining state equations include dynamics of, vehicle’s longitudinal and lateral velocities, yaw rate, rotational speeds of tires, and the air mass in intake manifold of engine respectively.

\[ \dot{V}_l = \frac{1}{m} \left[ (F_{fl} + F_{fr}) \cos \delta - (F_{rr} + F_{rl}) \sin \delta + F_{fr} - F_{rr} - F_{rl} + mV_r \right] \]  
\[ \dot{V}_r = \frac{1}{m} \left[ (F_{fl} + F_{fr}) \cos \delta + (F_{rr} + F_{rl}) \sin \delta + F_{fr} - F_{rr} - F_{rl} - mV_r \right] \]  
\[ \dot{r} = \frac{1}{I_z} \left[ (F_{fl} - F_{fr}) l_f \sin \delta + (F_{rr} - F_{rl}) l_r \cos \delta + (F_{rr} - F_{rl}) l_r \sin \delta + (F_{fl} - F_{fr}) l_f \cos \delta \right] \]  
\[ \dot{\omega}_y = \frac{2}{J + N J_{eff}} \left[ \frac{N}{2} + T_{sys} - T_{loss} - R F_{fl} \right] \]  
\[ \dot{\omega}_x = \frac{2}{J + N J_{eff}} \left[ \frac{N}{2} + T_{sys} - T_{loss} - R F_{fr} \right] \]  
\[ \dot{\omega}_x = \frac{1}{J} \left[ T_{sys} - R F_{fr} \right] \]  
\[ \dot{\omega}_y = \frac{1}{J} \left[ T_{sys} - R F_{fl} \right] \]  
\[ m_e = m_{\text{ref}} - m_{\text{eff}} \]  

Longitudinal Controller

In longitudinal controller the controlled variable is chosen as longitudinal slip ratio and input variable as engine throttle angle. By defining the slip ratio tracking error and the longitudinal sliding surface by:

\[ e_l = s_l - 1 \]  
\[ s_l = s_l + ae_e \]  

Using the super twisting algorithm of second order sliding mode method, control input TC [10] which is a simple function of throttle angle is computed by following relations:

\[ TC = \frac{u}{x_s}, u = -\eta \sqrt{s_l} \text{sign}(s_l) + u \]  

In these equations \( s_l \) is a defined function of the system state variables, and \( \omega_1 \) and \( \eta \) are controller parameters.

Lateral Controller

Similar to longitudinal controller, lateral controller is defined as bellow
\[ u = -\eta_a \sqrt{s_a} \text{sign}(s_a) + u_a \]  
(11)

Where \( u_a = -\omega_s \text{sign}(s_a) \), \( \omega_s \) and \( \eta_a \) are controller parameters and \( s_a \) is the sliding variable of lateral controller defined by:

\[ s_a = r - r_i - \alpha \]  
(12)

**Mixed Controller**

The longitudinal and lateral controllers were initially designed separately and mixed controller system was designed based on them.

**3. Simulation Results**

Vehicle is considered initially moving along x-axis which is followed by applying the steering angle. Figure 1 shows the resulting vehicle path compared between controlled system and open loop system. The optimal amount of desired longitudinal slip is considered as \( \lambda_d = 0.1 \). Figure shows controller performance in following the desired path. Figure 4, shows the applied yaw moment \( M_z \) by the controller.

![Vehicle Path: controlled vs. open loop](image1)

**A. Vehicle path: controlled by mixed controller vs. desired path**

**B. Vehicle path: open loop vs. desired path**

![Vehicle Path: open loop vs. desired path](image2)

**Figure 1. Vehicle Path: controlled vs. open loop**

**4. Conclusions**

In this paper, mixed longitudinal and lateral controller design was developed for the system in three stages. The longitudinal and lateral controllers were initially designed separately. Finally, mixed controller system was designed based on them. Engine dynamics was also taken into account in controller computations. Engine throttle angle was computed by using only one sliding surface which reduces computational cost of the controller. Simulation results shows the mixed controller good performance in correcting the open loop system defects.

![Figure 2. Yaw moment applied by the lateral controller](image3)

**5. References**


