Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(2) (2021) 229-232
DOI: 10.22060/mej.2020.16337.6345

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

S. Namdari, S. Rezapour Khaneghah, M. A. Hamed*

Department of Mechanical Engineering, University of Tabriz, Tabriz, Iran

ABSTRACT: Vehicle stability control is one of the most important subjects in the 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 tires 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 a 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 a complicated vehicle dynamic model and multiple disturbances in vehicle motion. Engine throttle angle and yaw moment have been considered as a longitudinal system and lateral system control inputs respectively. The longitudinal slip coefficient and yaw rate are considered as system output. Simulation results show the effectiveness of the proposed method.

Review History:

Received: May, 18. 2019
Revised: Sep. 11, 2019
Accepted: Dec. 29, 2019
Available Online: Jan. 13, 2020

Keywords:

Vehicle stability
Mixed longitudinal and lateral stability
Dugoff tire model
Cho motor model
Super-twisting algorithm

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 the 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 a 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 (AFS) method 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 an internal mode control method to improve vehicle yaw rate dynamics and Liaw and Chung [5] applied a feedback linearization technique for vehicle lateral stability. Zhao et al. [6] designed a 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 the vehicle [7] is considered to extract the dynamic equations. Dugoff's nonlinear model has been used to simulate the behavior of tire 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 a super-twisting algorithm [9]. The throttle angle is computed by using one sliding surface resulting in a reduction in the computational cost of the controller.

2. PROBLEM FORMULATION

Differential equations governing vehicle and engine dynamics are given through Eqs. (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 drives through differential gear. The kinematic coupling between the engine and front wheels imposes kinematic constraints between front wheels speeds and engine speed, which eliminates one of the 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 the intake manifold of engine respectively.

*Corresponding author's email: ma.hamed@tabrizu.ac.ir

$$\dot{V}_x = \frac{1}{m}\Big[\left(F_{xfl}+F_{xfr}\right)\cos\delta - \left(F_{yfl}+F_{yfr}\right)\sin\delta + F_{xrl}+F_{xrr}-F_{loss}+mV_y r\Big] \quad (1)$$

$$\dot{V}_y = \frac{1}{m}\Big[\left(F_{yfl}+F_{yfr}\right)\cos\delta + \left(F_{xfl}+F_{xfr}\right)\sin\delta + F_{yrl}+F_{yrr}-mV_x r\Big] \quad (2)$$

$$\dot{r} = \frac{1}{I_z}[\left(F_{yfl}-F_{yfr}\right)l_s\sin\delta + \left(F_{xfr}-F_{xfl}\right)l_s\cos\delta + \left(F_{xrr}-F_{xrl}\right)l_s - \left(F_{yrl}+F_{yrr}\right)l_r + \left(F_{xfr}+F_{xfl}\right)l_f\sin\delta + \left(F_{yfr}+F_{yfl}\right)l_f\cos\delta] \quad (3)$$

$$\dot{\omega}_{fr} = \frac{\frac{T_{ind}-T_{loss}}{2} - \frac{R.F_{xfr}}{N}}{\frac{J}{N}+\frac{N\,J_{eff}}{2}} \quad (4)$$

$$\dot{\omega}_{fl} = \frac{\frac{T_{ind}-T_{loss}}{2} - \frac{R.F_{xfl}}{N}}{\frac{J}{N}+\frac{N\,J_{eff}}{2}} \quad (5)$$

$$\dot{\omega}_{rr} = \frac{1}{J}\left[T_{rr}-R.F_{rr}\right] \quad (6)$$

$$\dot{\omega}_{rl} = \frac{1}{J}\left[T_{rl}-R.F_{rl}\right] \quad (7)$$

$$\dot{m}_a = \dot{m}_{ai} - \dot{m}_{ao} \quad (8)$$

2-1- Longitudinal Controller

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

$$e_l = \lambda_f - \lambda_d$$
$$s_l = \dot{e}_l + \alpha e_l \quad (9)$$

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 the following relations:

$$TC = \frac{u}{x_5},\ u = -\eta_l\sqrt{|s_l|}\,sign\left(s_l\right)+u_l \quad (10)$$
$$\dot{u}_l = -\omega_l\,sign\left(s_l\right)$$

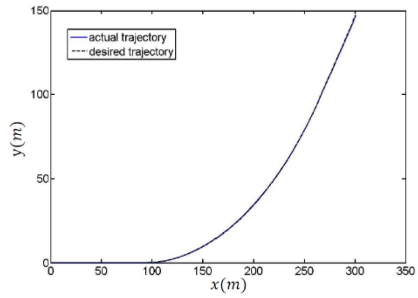
In these equations x_5 is a defined function of the system state variables, and ω_l and η_l are controller parameters.

2-2- Lateral Controller

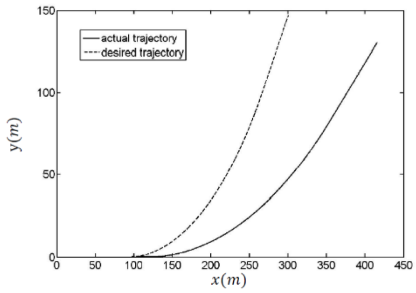
Similar to the longitudinal controller, the lateral controller is defined as bellow:

$$u = -\eta_a\sqrt{|s_a|}\,sign\left(s_a\right)+u_a \quad (11)$$

where $\dot{u}_a = -\omega_a sign\left(s_a\right)$, ω_a and η_a are controller parameters and s_a is the sliding variable of lateral controller



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



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

Fig. 1. Vehicle path: controlled vs. open-loop

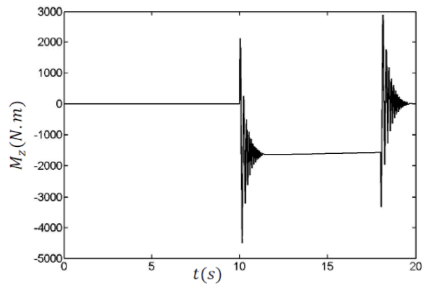


Fig. 2. Yaw moment applied by the lateral controller

defined by:

$$s_a = \dot{e}_a + \alpha e_a,\ e_a = r - r_d \quad (12)$$

2-3- Mixed Controller

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

3. SIMULATION RESULTS

The vehicle is considered initially moving along the x-axis which is followed by applying the steering angle. Fig. 1 shows the resulting vehicle path compared between the controlled system and the open-loop system. The optimal amount of the desired longitudinal slip is considered $\lambda_d = 0.1$. The Figure shows controller performance in following the desired path. Fig. 2, shows the applied yaw moment M_z by the controller.

4. CONCLUSIONS

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

REFERENCES

[1] S. Drakunov, U. Ozguner, P. Dix, B. Ashrafi, ABS control using optimum search via sliding modes, IEEE Transactions on Control Systems Technology, 3(1) (1995) 79-85.

[2] H. Lee, M. Tomizuka, Adaptive vehicle traction force control for intelligent vehicle highway systems (IVHSs), IEEE Transactions on Industrial Electronics, 50(1) (2003) 37-47.

[3] M. Kabganian, R. Kazemi, A new strategy for traction control in turning via engine modeling, IEEE Transactions on Vehicular Technology, 50(6) (2001) 1540-1548.

[4] M. Canale, L. Fagiano, M. Milanese, P. Borodani, Robust vehicle yaw control using an active differential and IMC techniques, Control Engineering Practice, 15(8) (2007) 923-941.

[5] D.-C. Liaw, W.-C. Chung, A feedback linearization design for the control of vehicle's lateral dynamics, Nonlinear Dynamics, 52(4) (2008) 313-329.

[6] H. Zhao, W. Chen, J. Zhao, Y. Zhang, H. Chen, Modular Integrated Longitudinal, Lateral, and Vertical Vehicle Stability Control for Distributed Electric Vehicles, IEEE Transactions on Vehicular Technology, 68(2) (2019) 1327-1338.

[7] D.E. Smith, J.M. Starkey, Effects of model complexity on the performance of automated vehicle steering controllers: Model development, validation and comparison, Vehicle System Dynamics, 24(2) (1995) 163-181.

[8] D. Cho, J. Hedrick, A nonlinear controller design method for fuel-injected automotive engines, Journal of Engineering for Gas Turbines and Power, 110(3) (1988) 313-320.

[9] Y. Shtessel, C. Edwards, L. Fridman, A. Levant, Sliding mode control and observation, Springer, 2014.

HOW TO CITE THIS ARTICLE

S. Namdari, S. Rezapour Khaneghah, M. A. Hamed, Control of Vehicle's Mixed Longitudinal and Lateral Stability with Engine Dynamics Using Super Twisting Control Algorithm, Amirkabir J. Mech. Eng., 53(2) (2021) 229-232.

DOI: 10.22060/mej.2020.16337.6345