Coordinated Control of Electronic Stability Program and Active Front Steering

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Abstract

In this paper, the coordinated control system is proposed to improve vehicle handling and stability by coordinating control of Electronic Stability Program (ESP) and Active Front Steering (AFS). Firstly, we calculated the target yawing moment required to keep the vehicle stable according to PID control of the yaw-rate. Secondly, we proposed a fuzzy method to control Electronic Stability Program and Active Front Steering, then we used genetic algorithm to optimize the control rule to ensure the correctness and accuracy of the control rule. The performance of the integrated control system is evaluated by Computer simulations at two different running condition, we compared the performance of the integrated system with other situations such as only AFS control, only ESP control and no control. The results show that the method proposed in this paper is able to improve the driving dynamics and steering stability of the vehicle effectively.

Keywords - Coordinated control; Active front steering; Electronic stability program; Fuzzy control; genetic algorithm

1. Introduction

With the rapid development of automobile industry and the improvement of the speed, active safety control technology obtained a rapid development, it can improve the operation stability and the safety in the process of automobile vehicle driving, but the integrated control of electric control subsystem also produce two big main questions: (1) The automobile hardware and software get more complicated as a result of the use of more and more sensors. (2) The control objects of some electronic control system are same so that they get conflict unavoidably in their separate control goal. In order to solve these problems, the chassis integrated control technology obtained a rapid development in nearly 20 years. Chassis integrated control can deal with two and above electronic control systems according to the control of software and hardware behavior and target. Chassis integrated control can improve the vehicle dynamic performance and reduce the number of sensors and actuators.
Researches showed that Active Front Steering (AFS) system has been generally applied for the conditions of steady-state. The vehicle dynamics display nonlinear characteristics when the lateral tire forces reach their adhesion limits, so AFS system becomes less effective. While vehicle dynamic stability can be improved by Electronic Stability Program (ESP) system even though tire lateral forces approach their limits. But ESP adds the burden of the driver in cornering and decreases steady-state value of yaw rate at high speed. This trend can be balanced by the AFS. So ESP combined with AFS control can further improve vehicle handling and stability.

Scholars both at home and abroad make an extensive research on the chassis integrated control. Reference [1] determined the target yawing moment according to the control of the deviation between the actual status and ideal status. Then the target yawing moment is allocated to the front wheel active steering system and electronic stability system according to the actual status of the vehicle to realize the coordinated control of two systems. Reference [2] realized the control of ESP based on status feedback and the control of AFS based on sliding mode. Reference [3] proposed AFS control strategy based on sliding mode and ESP control strategy based on yawing moment with transient slip rate joint control. Reference [4] investigated the integration of various subsystems of an automobile’s chassis. The specific focus of this research was the integration of active suspension components with Antilock Braking System mechanisms.

In this paper, the integrated control of AFS and ESP in vehicle is investigated. Its organization is as follows: In Section II, the 2 DOF monorail model is established in order to determine the nominal yaw-rate. In Section III, the target yawing moment required to keep the vehicle stable is calculated according to PID control of the yaw-rate. In Section IV, the fuzzy control strategy is applied and genetic algorithm is used to optimize the fuzzy control rule. Then the target yawing moment is allocated to the front wheel active steering system and electronic stability system. Conclusions is finally made in Section V, and the comparison is made in the case of only AFS control and only ESP control.

2. Establishment of the 2 Dof Monorail Model

The 2 DOF monorail model

The dynamic equation of the liner 2DOF monorail model can be shown in (1):

\[
\begin{align*}
 mV \left( \beta + \gamma \right) &= F_{yf} + F_{yr} \\
 I' \gamma &= F_{yf} \times l_f - F_{yr} \times l_r
\end{align*}
\]

(1)

The lateral force beared by the front wheel and the rear wheel have a linear relationship with the corresponding lateral angle, expressed as:
\[
\begin{align*}
\begin{cases}
F_{yf} &= c_{af} \cdot \alpha_f \\
F_{yr} &= c_{ar} \cdot \alpha_r \\
\end{cases}
\end{align*}
\]  
(2)

Where,
\[
\begin{align*}
\alpha_f &= \delta_f - \frac{V_y + l_f \cdot \gamma}{V_x} \\
\alpha_r &= \frac{V_y - l_r \cdot \gamma}{V_x} \\
\end{align*}
\]  
(3)

The stable cornering state of the linear 2 DOF vehicle is viewed as the ideal state of the stability of vehicle. Then the yaw-rate at ideal state of the linear 2 DOF vehicle is viewed as the nominal yaw-rate of the car.

\[
\gamma_{NO} = \frac{V_y \cdot \tan \delta_f}{l \cdot \left[1 + \left(\frac{V_y}{V_{ch}}\right)^2\right]} \\
\]  
(4)

Where, \(V_{ch}^2 = \frac{c_{a_l}c_{a_r}l^2}{m(c_{a_l}l - c_{a_r}l_f)}\)  
(5)

Where, \(\delta_f\) - The steering wheel Angle  
\(V_y\) - The longitudinal velocity  
\(V_y\) - Horizontal speed  
\(l\) - Wheelbase  
\(i_L\) - Steering transmission ratio  
\(V_{ch}\) - Feature speed  
\(l_f\) - Distance from the front axle to centroid  
\(l_r\) - Distance from the rear axle to centroid  
\(c_{af}\) - Cornering stiffness of front axle  
\(c_{ar}\) - Cornering stiffness of rear axle

3. PID Controller Design

In this part, the target yawing moment is determined according to the PID control of yaw-rate. Fig. 2 show the control system.

In the figure, the nominal yaw-rate \(\gamma_{NO}\) in section II has been introduced, the deviation between the yaw-rate coming from the sensors of the vehicle and the nominal yaw-rate is viewed as the input of the controller. Then the PID controller calculated the value of the required target yawing moment according to the change of the input.

The input of the controller is the deviation between the yaw-rate coming from the sensors of the
vehicle and the nominal yaw-rate, through the adjustment to the three parameters of the PID controller, the target yawing adjusting torque is obtained. This paper used incremental PID control:

$$M = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt}$$  \hspace{1cm} (6)

Where, $e(t) = \gamma_{NO} - \gamma$, $\gamma_{NO}$ is the ideal yaw-rate, $\gamma$ is actual yaw-rate, $K_p$ is proportional control coefficient, $K_i$ is integral control coefficient, $K_d$ is differential control coefficient.

The three parameters of the PID controller can be gotten through repeated debugging.

4. Coordinated Controller Design

The distribution expression for Target yawing moment is:

$$M = M_1 + M_2$$  \hspace{1cm} (7)

Where, $M_1 = qM$, $M_2 = (1-q)M$.

$q$ is coordinated control parameter. The role of coordinated control parameter q is to control the working intensity AFS and ESP. The coordinated control rule is: When AFS control independently, $q = 1$; When ESP control independently, $q = 0$; When two subsystems are in coordination control, $q$ have different values according to the different states of vehicle. In the process of the coordinated control of AFS and ESP, the value of $q$ is adjusted according to the different vehicle states to keep the vehicle always has good stability and maneuverability. This paper determines coordination parameter through fuzzy control method.

4.1 The input and output of the fuzzy controller

In this paper, the input variables are $\Delta \beta$ ( $\Delta \beta = \beta - \beta_{NO}$ ), $\Delta \gamma$ ( $\Delta \gamma = \gamma - \gamma_{NO}$ ).

Where $\beta_{NO}$ = 0, the output variable is $q$. The Fuzzy sets and domain definitions of $\Delta \beta, \Delta \gamma, q$ are defined as follows:

The fuzzy sets of $\Delta \beta, \Delta \gamma, q$ are the same as follow:

{NG, NM, NS, ZO, PS, PM, PG}

In the above definition, NG means negative big, NM means negative middle, NS means negative small; ZO means zero, PS is positive small, PM means positive middle, PG means positive big.

The domain definition of $\Delta \beta$ is [-1.8 1.8], the domain definition of $\Delta \gamma$ is [-6 6], the domain definition of $q$ is [0 1]. Take triangle distribution as the membership function of $\Delta \beta, \Delta \gamma$. The membership function is as follows:

![The membership function of $\Delta \beta$](image)

![The membership function of $\Delta \gamma$](image)
4.2 The Determination Of The Fuzzy Controller Control Rule

Control rule is commonly adopted by the way of experiment adjustment or experience of the expert. Because of the limited experience and the complexity of experiment adjustment, this paper use genetic algorithm to optimize the control rule to ensure the correctness and accuracy of the control rule. At last makes fuzzy controller achieve optimal.

Whether the Fuzzy controller performance can achieve optimal can be characterized by target function that reflects the vehicle state. In this paper, the deviation between the actual side slip angle and the nominal side slip angle \( \beta - \beta_{NO} \) (the nominal side slip angle is 0), the deviation between the actual yaw-rate and the nominal yaw-rate and the side slip angle rate, \( \beta \) are used to make up the target function of the genetic algorithm. The target function of the genetic algorithm is

\[
Q = \sum_{i=1}^{N} (q_1 |\Delta \beta| + q_2 |\Delta \gamma| + q_3 |\beta|) / N
\]

Where, \( q_1 \), \( q_2 \), \( q_3 \) separately stands for corresponding variable weight coefficient, \( N \) is maximum sampled points. The target function \( Q \) carry on the comprehensive evaluation for coordinated control system performance, the smaller \( Q \) is, the better the performance of the coordinate control system is.

This paper optimizes the fuzzy control rule through programming based on the fuzzy control toolbox and genetic algorithm toolbox provided by MATLAB/Simulink. the specific implementation steps are as follows:

1) First of all, the linguistic value of the output language variables are coded for \( q_1 \), \( q_2 \), \( q_3 \), \( q_4 \), \( q_5 \), \( q_6 \), \( q_7 \), and the decimal part between every integer fetch the whole operation. For example, when \( x=1.2 \), \( x \) is integered as 1. And the corresponding fuzzy rule is: if \( \Delta \beta \) is NB and \( \Delta \gamma \) is NB then \( q \) is NB. The scope of optimized variables is \( [1, 7] \), all the optimized variables are composed of a set. There are 49 optimization variables and separately correspond 49 fuzzy rules.

2) Simulink is used to establish 2 DOF monorail vehicle model. Then coordinated control parameters are adjusted according to the formula and the above fuzzy control.

3) Write the optimized target M file of the genetic algorithm, the functions such as the calculation of objective function value of the Genetic algorithm, the modification of the fuzzy rule, the simulation of vehicle 2 DOF monorail model, the output of the result and so on are realized by this M file.

4) call for the target M file By using the genetic algorithm toolbox, randomly select 50 individual as the initial population, genetic algorithm toolbox modify fuzzy rules through target M document according to each individual's initial variable values and the vehicle 2 DOF monorail model is simulated. Calculate the objective function value of each individual According to the calculation formula (8), the smaller the value of the formula (8) is, the bigger the individual fitness is. Make selecting, crossover and mutation operation according to the fitness of each individual and generate the next generation. Modify fuzzy rules again according to the value of each new individual variable, and calculate the fitness of each individual.
Among them, the crossover probability is 0.7 and the mutation probability takes 0.3, the method of choice uses "gamble in turn" rule, the biggest genetic generation is 100.

5) If the target function satisfies the condition of error convergence then we are sure to get the optimal individual, and stop calculation, otherwise repeat step (4) until the biggest genetic algebra.

5. Simulation and Results

The performance of the integrated control system is evaluated by Computer simulations. In the process of simulations, we compare the performance of the integrated system with other situations: only AFS control, only ESP control and no control.

The first simulation is in the condition of a single move line running, where road friction coefficient is 0.85, the speed is 120km/h, the steering wheel Angle is 73deg / 0.5 Hz. The simulation results are shown in Fig.4.

![Vehicle path](image)

![Yaw rate](image)

![Side slip angle](image)

Simulation experiment results show that the driver completed the single move line operation better under the condition of the integrated control, the results illustrates the coordinated control system can help driver steady vehicles, the yaw-rate and side slip angle are smaller in the coordinated control.

The second simulation is in the condition of square wave running, where road friction coefficient is 0.4, the speed is 80km/h, The simulation results are shown in Fig.5.
Simulation experiment results show that the driver completed square wave running better under the condition of the integrated control, the result explains the coordinated control system can help driver steady vehicles, the yaw-rate and side slip angle are smaller in the coordinated control.

Acknowledgment

In this paper, the integrated control system that coordinates AFS and ESP is proposed to improve the performance of handling and stability. The target yawing moment required to keep the vehicle stable is calculated according to PID control of the yaw-rate. The fuzzy control strategy is applied and genetic algorithm is used to optimize the fuzzy control rule. Then the target yawing moment is allocated to the front wheel active steering system and electronic stability system. We can draw a conclusion from the simulation results, the integrated control system is able to improve the driving dynamics and steering stability of the vehicle effectively.
References


