Adaptive Control Research Based on Differential Drive Active Steering of Electric Vehicle

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ABSTRACT: In order to prevent the four-wheel independent drive electric tricycle in differential drive active steering to understeer or oversteering. It is necessary to control the vehicle, thus setting up four degrees of freedom vehicle model and using the MRAC control strategy to control vehicle. Using simulink software set up the electric wheel vehicle control model and simulate the model so as to analysis single input quantity before and after the control effects on a single output. The simulink simulation show that the electric tricycle can quickly reach the stable state under the adaptive control, transient response quality is good, and the system has strong adaptive ability and robustness.

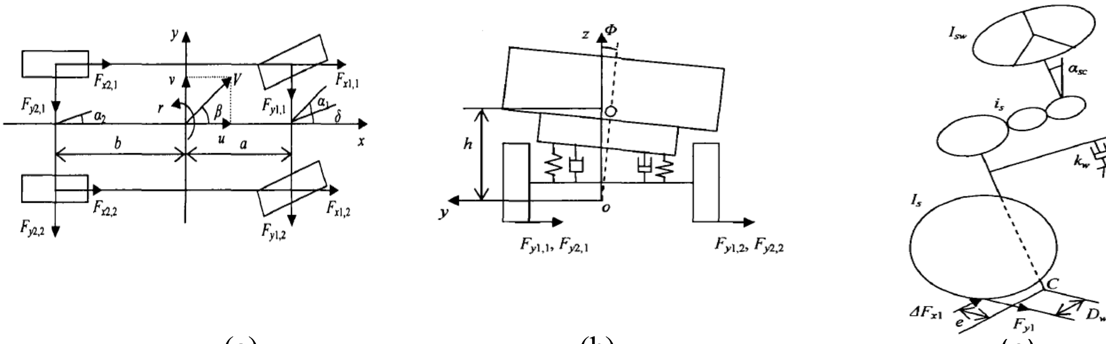
INTRODUCTION

Since the four wheeled electric wheeled vehicle is controlled in the steering time，According to the characteristics of the speed and torque of the electric wheel can be controlled independently，The mechanism of differential force active steering is proposed.，The control of the active steering control and the direct yaw moment control is used in most of the literatures，The control strategy can make the electric wheel get better transient response when steering，But control parameters adjustment is more complex，In this paper, the model reference adaptive control is designed by Lyapunov stability method，The model reference adaptive control can effectively achieve good control results according to the reference model，And can compensate the complex nature of parameter adjustment，When the electric wheel steering，the wheel can obtain good transient quality.

VEHICLE MODEL

construct The four degree of freedom vehicle model

Because the driving force about left and right front and rear wheel is not equally，The model adds the difference of longitudinal force about the left rear wheel as the input of the vehicle model .Assuming that vehicles driving at a constant speed, Ignore the vertical vibration of the vehicle,The influence of the nonlinearity and aerodynamic force of the tire on the lateral force and torque of the vehicle.Establish the following linear vehicle dynamics model,As shown in Figure 2.1.



(a) (b) (c)

Fig. 2.1 dynamic model of linear vehicle

By Newton second law,The dynamic equations of the vehicle with four degrees of freedom can be obtained.

$$I_z\dot{r}+I_{xz}\ddot{f}+aF_{y1}-bF_{y2}+\Delta F_{x1}\frac{B_f}{2}+\Delta F_{x2}\frac{B_r}{2}=0 \qquad (1)$$

$$(M_T-M_S)(r+\dot{b})V+M_S[V(r+\dot{b})-h\ddot{f}]+F_{y1}+F_{y2}=0 \qquad (2)$$

$$I_x\ddot{f}-M_shV(r+\dot{b})+I_{xz}\dot{r}+(D_f+D_r)\dot{f}+(C_{f1}+C_{f2}-M_shg)f=0 \qquad (3)$$

$$[T_{sw}-I_{sw}(\ddot{d}_{sw}+\dot{r}\cos a_{sc}-\ddot{f}\sin a_{sc})]i_s+F_{y1}D_w-I_s\ddot{d}-K_w\dot{d}-C_wd-\Delta F_{x1}e=0 \qquad (4)$$

In style:(1)For the torque equilibrium equation of the Z axis,(2)The force balance equation for the Y axis,(3)The torque equilibrium equation for the X axis is,(4)Around the swizzle torque balance equation

The state equation of the 4 degree of freedom linear vehicle

Will the dynamics differential equation for Fourier transform into state equation form,Vehicle parameters,Partial parameters see Table 1,The initial conditions are V=60km/h.The elements of the state vector x and the output vector y are: yaw velocity r,Centroid deflection angle of vehicle body b , Inclination angle of vehicle body $\dot{f}$, Side inclination of body f , Front wheel steering angle speed $\dot{d}$, Front wheel steering angle d 。U input vector:Steering wheel torque T_{sw} , Front wheel longitudinal force difference ΔF_{x1} , Left and right rear wheel longitudinal force difference ΔF_{x2} 。

$$\dot{x}=Ax+BU \qquad (5)$$

$$y=Cx \qquad (6)$$

$$A=\begin{bmatrix} -5.17 & 8.97 & 0.06 & -2.17 & 0 & -27.12 \\ -0.93 & -6.38 & -0.17 & -2.45 & 0 & 3.52 \\ 0.97 & 73.57 & -9.28 & -135.10 & 0 & 41.17 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 11.52 & 181.42 & -0.28 & 5.14 & -7.86 & -182.05 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & -0.0003 & -0.0003 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.67 & -0.0016 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$C=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

MRAC controller design

Model reference adaptive control law

Assume four degrees of freedom vehicle dynamics differential equation described as follows：

$$\dot{x} = Ax(t) + Bu(t) \tag{7}$$

In style: $x(t) \in R^n$ is Vehicle state vector； $u(t) \in R^n$ is Comprehensive control of vector;A is the state matrix of the vehicle；B is the input control matrix。The vehicle reference model of the hope can be defined as：

$$\dot{x}_m = A_m x_m(t) + B_m u_m(t) \tag{8}$$

In style $x_m(t) \in R^n$ is state vector of the reference model,The error between the reference model and the controlled model is defined as:

$$e(t) = x_m(t) - x(t) \tag{9}$$

The error state differential equation is changed to

$$\dot{e}(t) = A_m e(t) + u_0(t) - Ax(t) \tag{10}$$

In style:

$$u_0 = A_m x(t) + B_m u(t) - Bu(t) \tag{11}$$

By the Lyapunov second method to design adaptive control law

$$u(t) = B^+[A_m x(t) + B_m u_m(t) - u_0(t)] \tag{12}$$

Adaptive law to design adaptive mechanism by Lyapunov stability theory,Namely, by lyapunov second method with adaptive algorithm,To guarantee the adaptive global stability，So the control law based on the stability theory is globally stable,Reference [7] has been demonstrated.

Selection of reference models

The dynamic differential equations by the Fourier transform into the equation of state，And get the most ideal vehicle parameters into it，we can get the ideal reference model,Selection of optimal parameters checking computations.

$$\dot{x}_m = A_m x_m + B_m u_m \tag{13}$$

$$y = C_m x \tag{14}$$

$$A_m = \begin{bmatrix} -7.88 & 13.87 & 0.12 & -2.95 & 0 & 40.38 \\ -0.92 & -6.8123 & -0.22 & -3.24 & 0 & 3.7 \\ 1.39 & -97.51 & -12.27 & -178.67 & 0 & 51.35 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 15.52 & 244.11 & -0.37 & 7.03 & -10.58 & -246.56 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B_m = \begin{bmatrix} 0 & -0.0004 & -0.0004 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.8957 & -0.0022 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$C_m = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Simulation and analysis

Matlab/simulink software is used for simulation,The total control chart of the system is shown in Figure 4.1， Part of the simulation parameters see Table 1. MRAC control is the control strategy of the vehicle model completely following the reference model with the adaptive control law.,The principle diagram of the adaptive device can make the vehicle model state equation completely tracking the reference model of the state equation.

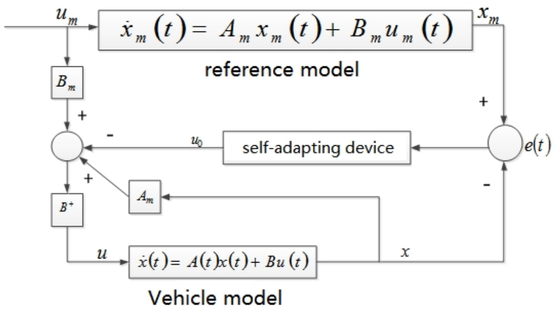


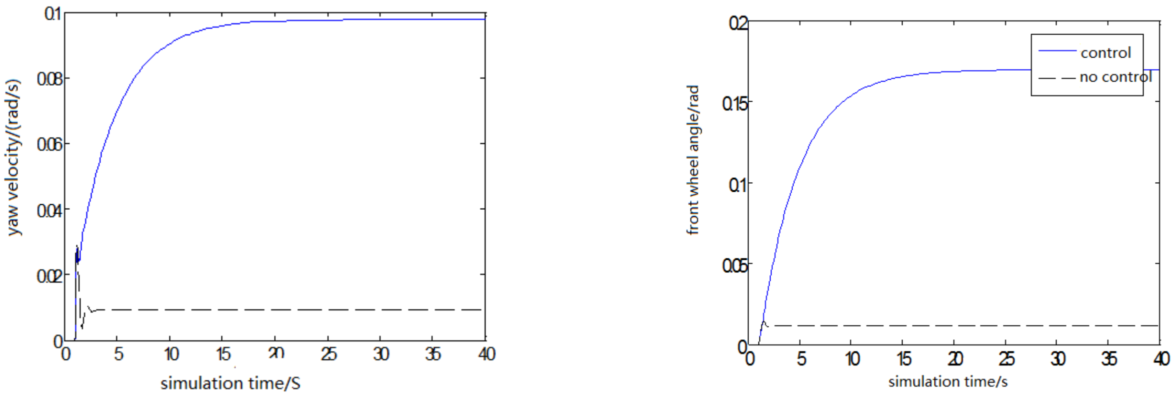
Figure 4.1 system of control block diagram

Table 1 part of the simulation parameters

Parameter	symbol	comppany	numerical
Total vehicle quality	Mt	Kg	1704.7
Yellow quality	Ms	Kg	1526.9
The centroid Distance to The front axle	a	m	1.035
The centroid Distance to The rear axle	b	m	1.655
Roll arm	h	m	0.3352
Front track	Bf	m	1.535
Rear wheel	Br	m	1.535

Figure 4.2 for The response of the system under control and uncontrolled which the step input of the front left wheel drive force difference are 2000N,The driver applied a torque of 0 to the steering wheel,The driving force difference of rear wheel is also 0. Figure (a) is the response of the yaw rate,Can be seen from the picture, the system starts to respond to the 1s,The convergence of the system is slow when there is no control,Great amount of overshoot,The time of the system oscillation is very long,In control time,System to 1.5s began to converge,The amount of overshoot is small,To reach the stable state at 3S,The oscillation decay duration is very short,About 1s systems converge to steady state.The amplitude of the oscillation is about 0.1 without control,The amplitude of the oscillation is about 0.02,Figure (b) is the response of front wheel steering angle,The

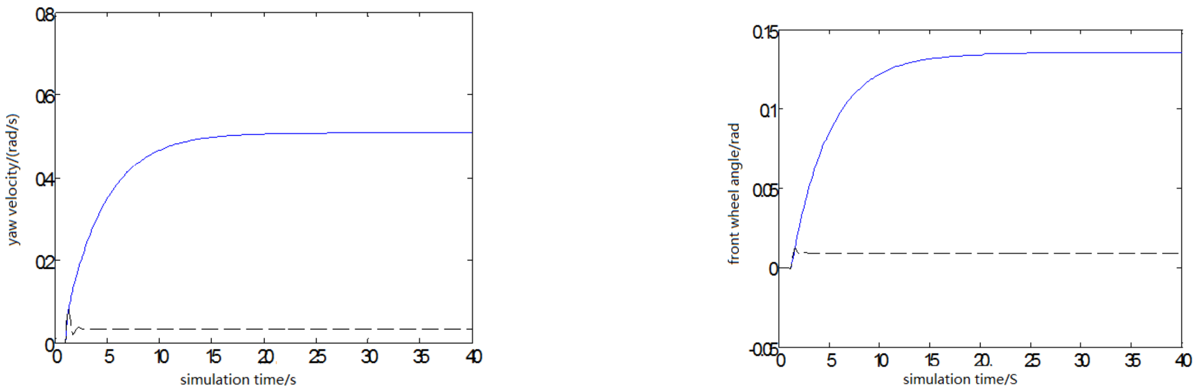
amplitude of the oscillation is small,Speed up the convergence,The oscillation amplitude of the control system is about 0.16, and the oscillation amplitude of the control system is fast,Under control,The oscillation amplitude of the system is reduced to 0.002.



(a) (b)

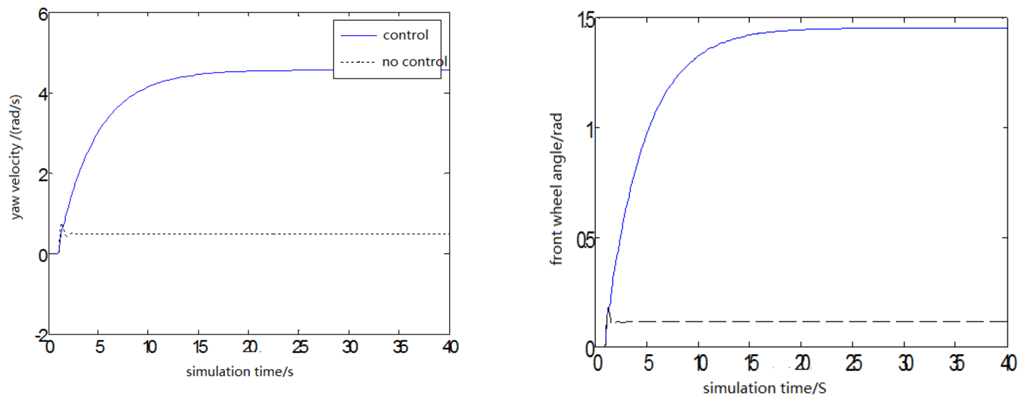
Fig. 4.2 the speed of the yaw rate and the front wheel angle of the 60km/h system

Vehicle speed at 60km/h,The response of the system to the response of the front wheel drive force difference is good when the speed of the vehicle is obviously high,See Figure 4.3 when the vehicle reaches 80km/h,The fluctuation of the response characteristic when the difference force active turn is slightly larger than the speed of the vehicle at 60km/h,The amplitude of the oscillation is higher than that of 60km/h,This vehicle steering angle with the same torque at high speed is more complete than the low-speed.See Figure 4.4 when the speed reaches 120km/h,The transient response of the system is poor,The amplitude of the oscillation is the maximum,Stable duration.But under the adaptive control,The transient response of the full speed system is still good.



(a) (b)

Fig. 4.3 the speed of the yaw rate and the front wheel angle of the 80km/h system



(a) (b)

Fig. 4.4 the speed of the yaw rate and the front wheel angle of the 120km/h system

Conclusion

Through the research on the model reference adaptive control which applied to electric vehicles,This study designs the adaptive control law,And the control model was established with Simulink,From the simulation analysis can be seen: The reference model of the model reference adaptive control is the difficulty of this research,And different reference models can get different control results,The stable state of the vehicle response is relatively fast when the vehicle response is relatively uncontrolled with the model reference adaptive control, And the transient response quality is better (if the overshoot is small, The decay of the oscillations is faster,Stable duration short)，The yaw rate of the vehicle system and the front wheel angle of the vehicle system are well received by the vehicle system,To prevent the vehicle from turning to the process of differential force active steering or the turning of the vehicle. The system has strong adaptive ability and robustness. Vehicle maneuverability has been improved. Under the adaptive control of this research design, Still able to compensate for the inadequacy of its response characteristics, The electric wheel car can get good response characteristic under the full speed.

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