The Optimal Control of Vehicle's Steering and Braking System

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Abstract. In order to make a research on the vehicle's ABS and AFS system, the fuzzy neural network controller was designed on the basis of the electric vehicle's steering and braking models. Then the genetic algorithms was used to improve the parameters of the membership function. For the purpose of the stability, the compensatory controller was designed . Finally, the Matlab/Simulink simulation software has been used in the simulation analysis. The result of simulation proves that no matter how working conditions changes, the designed system still has good tracking performance .The systemic robustness is more stronger and it also enhances the utility of the control system.

Introduction

In the evaluation of vehicle handling stability, the key two are the steering performance and braking performance. Both influence each other, restrict each other, and at the same time, both the stability is important index to evaluate the stability of vehicle chassis. Therefore, it is necessary to study the control stability when vehicle under the condition of steering braking. We can shorten the development cycle and reduce the cost of development by using the method of computer simulation. Therefore, this paper study the vehicle stability mainly by using computer simulation[1].

Vehicle Simulation Model

There are six degrees of freedom of movement when vehicle is regard as rigid body. They are, respectively, the longitudinal motion along the X axis, the roll motion around the X axis, the lateral motion along the Y axis, the pitch motion around the Y axis, the vertical motion along the Z axis and yawing motion around the Z axis[2].

The Vehicle Model. According to the dynamic analysis, there are the longitudinal balance equation of

the vehicle model:
$$\sum_{i=1}^{4} F_{xt}(i) = m(\dot{u} - v\gamma) \tag{1}$$

According to the dynamic analysis, there are the lateral balance equation of the vehicle model:

$$\sum_{i=1}^{4} F_{yt}(i) = m(\dot{v} + u\gamma) \tag{2}$$

According to the dynamic analysis, there are the yawing balance equation of the vehicle model:

$$J_z \cdot \dot{\gamma} = [F_{yt}(1)+F_{yt}(2)]\cdot a - [F_{yt}(3)+F_{yt}(4)]\cdot b + [F_{xt}(2)-F_{xt}(1)]\cdot\frac{d}{2} + [F_{xt}(4)-F_{xt}(3)]\cdot\frac{d}{2} \tag{3}$$

where: $F_{xt}(i) = F_x(i)\cdot\cos d(i) - F_y(i)\cdot\sin d(i)$, $F_{yt}(i) = F_x(i)\cdot\sin d(i) + F_y(i)\cdot\cos d(i)$.

The Vehicle Braking Model. The motion equation of vehicle is $-F_b = m\dot{u}$, the longitudinal adhesion is $F_b = m\cdot F_n$, the mathematical model of the wheel at the state of braking can be expressed as $I\dot{w} = F_b R - T_b$. Where, I is the moment of inertia that the wheel around the spin axis, $\dot{w}$ is the angular acceleration of the wheel around the spin axis and T_b is the braking torque of the wheel.

The Vehicle Steering Model. This paper describe the steering system by using two degree of freedom linear input model[3]: $\dot{x} = Ax + Bu$ (4)

where: $x = [b,g]^T, u = \Delta d, A = \begin{bmatrix} \dfrac{-(k_f + k_r)}{mv} & \dfrac{-1-(k_f a - k_r b)}{mv^2} \\ \dfrac{-(k_f a - k_r b)}{J_z} & \dfrac{-(k_f a^2 + k_r b^2)}{J_z v} \end{bmatrix}, B = [\dfrac{k_f}{mv} \quad \dfrac{k_f a}{J_z}]^T$

Where, b is the centroid sideslip angle, g is the yawing angular velocity, Δd is the additional angle of front wheel steering, k_f is the front wheel cornering stiffness and k_r is the rear wheel cornering stiffness.

Controller Design

Braking Controller Design. The overall block diagram of the brake controller is shown in Fig.1.The inputs are the error e and the error change rate ec, and their membership functions are taken from Gauss distribution. They are all described in seven linguistic fuzzy sets. The output variable of fuzzy controller is the torque error value $\Delta Tb = p \cdot e + q \cdot ec$.
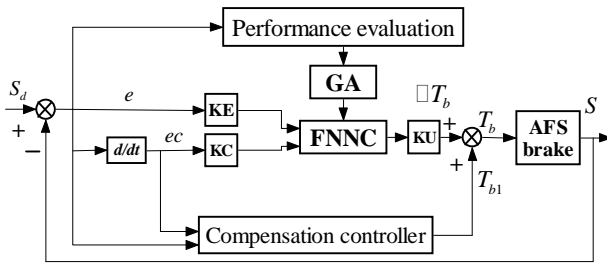

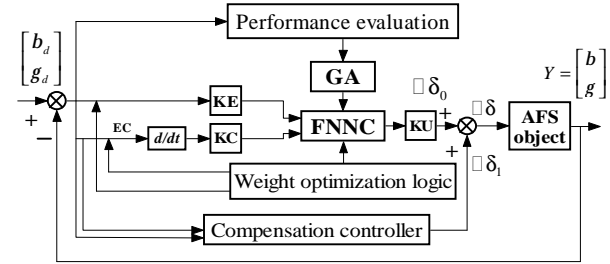Fig.1 The overall block diagram of braking controller

Fig.2 The overall block diagram of steering controller

In this paper, the normal distribution is used for the membership function, and parameters to be optimized is normal distribution variance p_1, p_2, p_3 and the mean value m_1, m_2, m_3. This paper using genetic algorithm to optimize membership function and encode the optimize parameters with 8-binary. The iterations is 100 and the group size is 40. The crossover operation is through two point crossover, and the crossing probability is 0.85. The mutation probability adopts adaptive mutation probability.

$$P_n = P_{na} + (P_{nb} - P_{na})\frac{f_{avg} - f_m}{f_{avg} - f_{min}}, f_m < f_{avg} \qquad (5)$$

$$P_n = P_{na}, f_m \geq f_{avg} \qquad (6)$$

Where, f_m is the chromosome fitness that is going to be a variation, f_{avg} is contemporary average fitness value and f_{min} is the minimum fitness value. $P_{na} = 0.01, P_{nb} = 0.2, P_n$ is the variation probability.

The fitness function： $f(t) = \int_0^T t|E(t)|dt \qquad (7)$

In this paper, the selection method is roulette method and achieve selection, crossover and mutation operator and calculation and calibration method of fitness function.

Steering Controller Design. The overall block diagram of the steering controller is shown in Fig.2.The two inputs $b_d - b, g_d - g$ are respectively the vector difference in the error vector E, and the other two are the error rates of the two errors. The variable are all described in five linguistic fuzzy sets. The output variable is additional steering angle error $\Delta\delta_0$.

Stability Design

Stability Design of Braking Controller. The derivative of slip ratio：

$$\dot{S} = (1 - S + \frac{mR^2}{I})\frac{\dot{v}}{v} + \frac{TbR}{Iv} \tag{8}$$

According to the total input and output relationship of the fuzzy neural network of the braking system above[4], there are the Eq.9:

$$\square Tb = \frac{\sum_{i=1}^{49}(p_i e + q_i ec) * \mu_{Rulei}}{\sum_{i=1}^{49}\mu_{Rulei}} = Kp \cdot e + Kd \cdot ec; (where, Kp = \frac{\sum_{i=1}^{49} p_i \cdot \mu_{Rulei}}{\sum_{i=1}^{49}\mu_{Rulei}}, Kd = \frac{\sum_{i=1}^{49} q_i \cdot \mu_{Rulei}}{\sum_{i=1}^{49}\mu_{Rulei}}) \tag{9}$$

Consideration of the role of compensation controller $Tb1$, and the controller general expression can be written as: $Tb = \square Tb + Tb1 = Kp \cdot e + Kd \cdot ec + Tb1$ (10)

Where $Tb1$ is the compensation controller that designed to stabilize system.

$$Tb1 = \frac{1 + B \cdot Kd}{B}(p1 - p2 - e \cdot p3 + k_0 \cdot e) \tag{11}$$

$$p1 = \frac{\dot{S}_d}{1 + B \cdot Kd}, p2 = \frac{\dot{v}(1 - S_d + \frac{mR^2}{I})}{(1 + B \cdot Kd)v}, p3 = [\frac{\dot{v}}{(1 + B \cdot Kd)v} + \frac{B \cdot Kp}{1 + B \cdot Kd}].$$

Where k_0 is positive variable parameter.

Structure Lyapunov Function $V(e) = \frac{1}{2}e^2$, and derivate it easily come to $\dot{V}(e) \le 0$. The theoretical analysis above can guarantee the system is asymptotically stable.

Stability Design of Steering Controller. Refer to the design stability of brake, the additional steering angle expression is shown in Eq.12.

$$\square \delta = Kp \cdot E + Kd \cdot EC + \square \delta 1 \tag{12}$$

The steering compensate controller can be designed:

$$\Delta \delta 1 = \frac{Q + k1 \cdot E^2 + k2 \cdot EC^2}{P} - Kp \cdot E - Kd \cdot EC \tag{13}$$

Where $k1$ and $k2$ are all positive number. $P = (\beta_d - \beta) \cdot b1 + (\gamma_d - \gamma) \cdot b2$,

$$Q = a1 \cdot (\beta_d - \beta)^2 + a4 \cdot (\gamma_d - \gamma)^2 + (\beta_d - \beta) \cdot \dot{\beta}_d + (\gamma_d - \gamma) \cdot \dot{\gamma}_d + (a2 + a3) \cdot (\beta_d - \beta) \cdot (\gamma_d - \gamma)$$
$$- [(\beta_d - \beta) \cdot a1 + (\gamma_d - \gamma) \cdot a3] \cdot \beta_d - [(\beta_d - \beta) \cdot a2 + (\gamma_d - \gamma) \cdot a4] \cdot \gamma_d \tag{14}$$

Structure Lyapunov Function: $V(E) = \frac{1}{2}E^T E = \frac{1}{2}(\beta_d - \beta)^2 + \frac{1}{2}(\gamma_d - \gamma)^2$ (15)

Derivation： $\dot{V}(E) = Q - P \cdot \Delta \delta \le 0$ (16)

The Lyapunov function is positive definite, its derivative is $\dot{V}(E) \le 0$, therefore this method can design the stability system.

Simulation Analysis

Simulation Analysis of Braking. In the single wheel braking, driving on the road that its adhesion coefficient is 0.8 at the initial speed of 30Km / h. The optimal slip ratio is set at 0.2[5].

Fig.3 is change chart of the vehicle speed and wheel speed when braking. After the start of braking, the adjustment time of wheel speed is short, the overshoot and the oscillation is small, and the tracking speed is relatively stable.

Figure 4 is the comparison chart of sliding ratio changes when vehicle braking under the control of PID and the control strategy in this paper, and the thick line is the control curve of this paper. The response speed is faster and the overshoot and the adjustment time is smaller than under the control of PID.
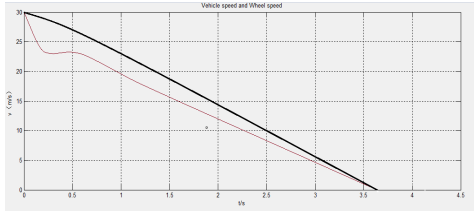

Fig.3 The curve chart of the vehicle
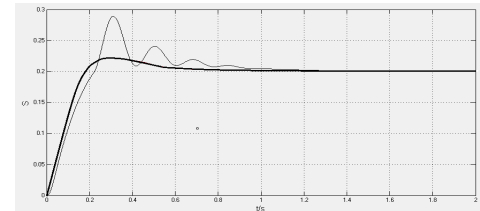speed and wheel speed change

Fig.4 The contrast curve of vehicle
braking slip ratio change

Verify the robustness of the controller in interference. The optimal slip rate is 0.2 when the brake is started, and the optimal slip rate is 0.4 after 1s.

Simulation Analysis of Steering. Driving on the road that its adhesion coefficient is 0.8 at the speed of 30Km / h for steering system simulation.

As shown in Fig.5, the response speed of side slip angle is fast, change smoothly, and the overshoot is small.
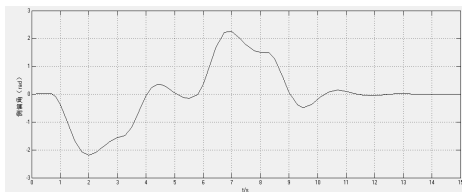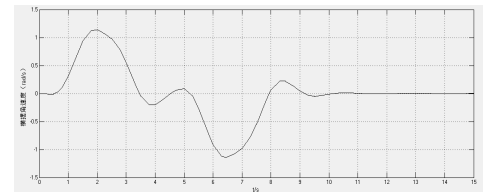

Fig.5 The sideslip angle change

Fig.6 The yaw rate change curve

Fig.6 is Vehicle yaw rate curve, the response time of yaw rate is in 1s,and the overshoot is small. This proves that the vehicle can be tracking the desired trajectory well under the control of controller designed in this paper.

Conclusions

Through the simulation results, the fuzzy neural network controller, which is optimized by the improved genetic algorithm, used in the vehicle steering and braking system, can enhanced braking stability obviously, the braking distance is shortened obviously, and the ideal steering trajectory can be traced, which can achieve the purpose of stable steering.

Acknowledgments

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