Study On the Assistant Steering Based On Fuzzy Control

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Abstract: Assistant steering controlling accuracy is important for automobile safety running. In order to gain the Ideal control targets of the assistant steering system, the real operating torque and ideal torque of steering wheel are adopted as the main control variable. In PD controller, the changing parameter is calculated inferentially by fuzzy logic. The real-time steering control voltage is dynamically corrected to approach the ideal steering torque. And the car yaw rate and slip angle is set as performance indicators as optimal objects of fuzzy PD controller. Using of genetic algorithm, the assistant steering system would be dynamically optimized. The assistant steering control method is verified by the computer simulation. The fuzzy PD controller with the genetic algorithm could effectively increase assistant steering controlling accuracy.

Keywords: assistant steering system; fuzzy control; genetic algorithm; multi-objects optimization

1. Introduction

With intelligent automobiles come into being, the accurate assistant steering controlling system is becoming an important factor to the safety running in different road environment with different running velocity[1,2,3]. The assistant steering system also better resolves contradiction between comfort and safety in steering system of conventional automobiles. The assistant steering control would increases the driver's steering safety and handling stability under complicated road condition[4,5]. The assistant steering system applied range extends from conventional automobiles to intelligent automobiles or even driverless automobiles[6,7]. The assistant steering controlling structure and control factors was optimized systematically. The fuzzy and genetic algorithm was used to fulfill integrated and matched in mechanical steering structures with different steering controller by domestic and foreign researchers.

In the assistant steering controlling system, the automobile steering structure and controlling model are built up by analysis of mechanical steering system. The decelerating structure parameters of steering system and PD controller was considered as optimizing factors. The fuzzy theory was adopted as dynamical adjusting controlling factors of PD controller. The outputting controlling voltage was adjusted and obtained with the objective steering torque. By using genetic method, the ideal steering torque of steering wheel were optimized. And the automobile yaw rate and sideslip angle were optimized at same time. The assistant steering controlling factors and controller optimized with genetic algorithm is simulated.

2. Steering System Structure

Considering automobile total weight, tire cornering stiffness and angle, the two-dimension automobile dynamical model is written as the formula(1) .

$$\begin{cases}(ak_1 - bk_2)\beta + 1/u(a^2k_1 + b^2k_2)\omega_r - ak_1\delta = I_z\dot{\omega}_r \\ (k_1 - k_2)\beta + 1/u(ak_1 + bk_2)\omega_r - k_1\delta = mu(\dot{\beta} + \omega_r)\end{cases} \quad (1)$$

The Matlab Simulink model built up based on the two-dimension automobile dynamical model is shown in Fig.1.

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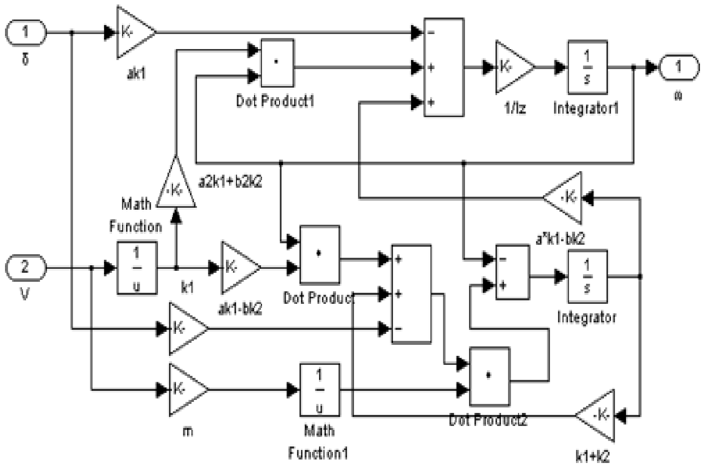

Fig. 1 Two-dimension automobile dynamical simulink model

In the formula(1) and Fig.1, m is the total weight; a is the front wheel base; b is the rear wheel base; k_1 is the front wheel cornering stiffness; k_2 is rear wheel cornering stiffness; β is the slipping angle of automobile; ω_r is the yaw rate; δ is steering angle; I_Z is automobile side slipping steering inertia; u is velocity.

Fiala theory is adopted as tire dynamic calculation model. The dynamic calculation model explains the relation of the tire cornering stiffness, slipping angle, vertical reaction force, and adhesion coefficient on road surface is written as formula (2).

$$K_i = K_i\left(1-\frac{1}{3}\frac{K_{si}}{\mu F_{zi}}+\frac{1}{27}\frac{(K_{si}\alpha_i)^2}{(\mu F_{zi})^2}\right) \quad (2)$$

In formula (2), $i(i=1,2)$ is the front or rear axle, K_{si} is the front or rear wheel static cornering stiffness, F_{zi} is vertical reaction force of front or rear axle. The vertical reaction force of front or rear axle is written as: $F_{z1}=Gb/(a+b), F_{z2}=Ga/(a+b)$. α_i is slipping angle of front or rear wheel. The slipping angle is written as: $\alpha_1=\delta_f-\beta-a\omega_r/v, \alpha_2=-\beta+b\omega_r/v$.

The gear rack steering structure with torque sensor, corner sensor, position sensor. i_1 is the ratio of motor to steering shaft. i_2 is the ratio of steering shaft to steering wheel. θ_m is assist motor angle. δ_1 is angle of reduction gears. So $\theta_m=i_1\delta_1$, $\delta_1=i_2\delta_f$. The steering calculation model is written as formula (3).

$$\begin{cases} J_p\dot{\delta_1}=B_p\delta_1+T_m-T_r+T_c \\ T_c=K_s(\theta_h-\delta_1) \\ T_r=2K_{1e}(\delta_1/i_2-a\,\omega_r/V-\beta)/i_2 \\ T_m=i_1K_a(V-K_b i_1\dot{\delta_1})/R \end{cases} \quad (3)$$

T_m is assistant torque of assist motor in steering system. T_c is driving torque of steering system. T_r is the torque to steering shaft as road reaction forces on the steering wheels. J_P is the inertia moment of reduction gears. B_p is the damping coefficient of steering system. K_S is torque stiffness of sensor; θ_h is wheel angle; K_1 is front wheel cornering stiffness; e is front wheel pneumatic trail; K_a is motor torque coefficient; k_b is back e.m.f.constant; R is motor resistance; V is motor voltage.

3. Steering System Optimization

Using of genetic calculation, steering structure factors, PD's proportion and differential coefficient are calculated and corrected. k_P is the proportion coefficient. k_D is the differential coefficient. E_{T_c}, E_{ω_r} and E_β is the goal variance, yaw rate total variance and the side slipping rate total variance respectively. The steering system optimization goal is written as formula (4).

$$\begin{cases} \min(w_1 E_{T_c}{}^2 + w_2 E_{\omega_r}{}^2 + w_3 E_\beta{}^2) \\ w_1 + w_2 + w_3 = 1 \\ k_{pmin} < k_p < k_{pmax} \\ k_{Dmin} < k_D < k_{Dmax} \\ i_{min} < i_1 < i_{max} \end{cases} \quad (4)$$

In formula (4), w_i is weight. $k_{Pmin}, k_{Dmin}, i_{min}$ is the lower limit of optimized variables, $k_{Pmax}, k_{Dmax}, i_{max}$ is the upper limit of optimized variables.

4. Fuzzy PD Controlling Simulation

The fuzzy PD steering controlling model composed of fuzzy controller and PID controller is shown in Fig. 2. The assistant motor voltage is controlled by the fuzzy PD steering controller referencing inputting data. The fuzzy PD controlling algorithm is written as formula (5). And the fuzzy PD steering controlling simulation model is shown as fig.2.

$$V_{ref} = k_p(T_c - T_{ref}) + k_D(\dot{T}_c - \dot{T}_{ref}) \quad (4)$$

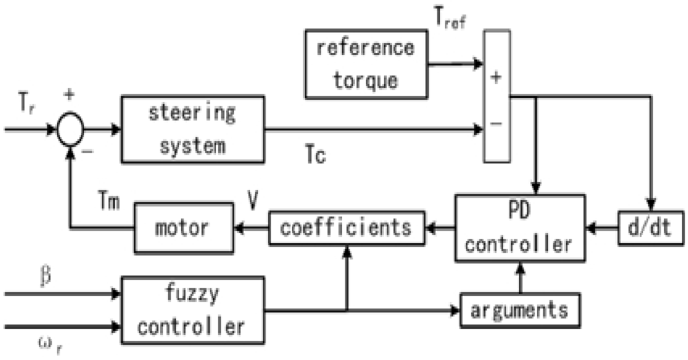

Fig. 2 Fuzzy PD controlling simulation model

The optimizing factors of fuzzy PD steering controlling model are k_P and k_D. Motor power inputting voltage is corrected with ω_r and β adjusted by fuzzy PD controller. As ω_r and β increasing, k_P and k_D coefficient is decreasing. So motor voltage inputting value is corrected in real time to keep steering action within safe limits.

5. Simulation Analysis

The fuzzy PD controlling simulation model is built up using of MatLab genetic algorithm. The simulation model can realize controlling coefficients' optimization and get global factors' optimization of steering system. Set standard torque as 6.2 NM, other factors are shown in table 1. Factor variation comparison after optimization is shown in table 2. Using of automobile steering testing bench, the steering controller based on fuzzy PD is simulated and verified.

Table1 Steering Controller Simulation Factors

factors	**Value**
Total weight m [kg]	8762
Side slipping steering inertia I_z [kg · m^2]	12790
Front wheel base a [m]	2.1
Rear wheel base b [m]	2.3
Front wheel cornering stiffness K_{s1} [N/ rad]	-63529
Rear wheel cornering stiffness K_{s2} [N/ rad]	-119184

Motor torque coefficient K_a [N · m/ A]	0.0698
Back e.m.f.constant k_b[V · s/ rad]	0.01
Motor resistance R [Ω]	0.14
Motor to steering shaft ratio i_1	19.8
Torque stiffness Ks [N · m/ rad]	85.8

Table2 Factors after Simulation Optimization

Factors	**Before Optimization**	**After Optimization**
Proportion Coefficient k_P	59.8	58.6
Differential Coefficient k_D	2.1	1.9
Ratio of steering shaft to steering wheel i_2	19.8	23.7

The side slipping angle summit value of steering system after training is reduced from 0.0378 rad to 0.0352 rad in Fig. 3. The variance decreases with 6.88% compared with before simulation. The side slipping angle is reduced respectively by 10.62% and 13.36% compared with mechanical steering system of no helping motor. And the automobile yaw rate summit value after optimization train is reduced to 0.0798 compared with yaw rate before training in Fig. 4. The yaw rate value is reduced by 2.86%. The variance is reduced by 4.47%. Compared with mechanical steering system of no helping motor, the yaw rate variance is reduced by 15.78%. After steering optimizing training of helping motor control, steering wheel torque can be effectively controlled within reference torque range[6.8,5.5] N·m. The steering wheel torque is kept within a stable range. The training analysis shows that assistant steering system with fuzzy PD can keep yaw rate and side slipping angle in the effectively and safe range.

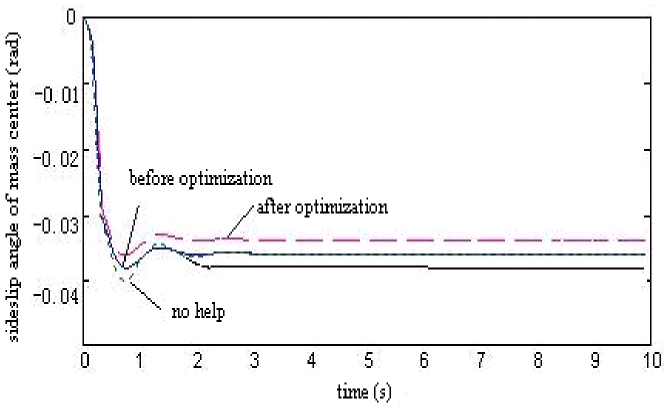

Fig.3 Side slipping angle comparison

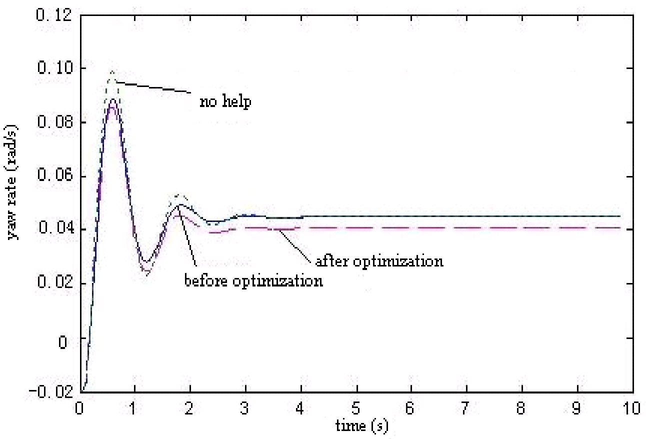

Fig.4 Yaw rate comparison

6. Conclusion

The assistant steering system with fuzzy PD controller is optimized by genetic algorithm. The steering torque, side slipping angle and yaw rate are set as optimize objectives of the genetic algorithm to multi-objective optimize steering system. Using of automobile steering testing bench, the steering controller based on fuzzy PD is simulated and verified. The results prove that assistant steering controller with fuzzy PD and the multi-objective optimized method is effective.

The optimized steering controller with fuzzy PD can reduce the side slipping angle, yaw rate and vibration effectively. The assistant steering controller is availably way to enhance stability and safety as automobile turning running direction.

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