Research on Automobile Rear-end System Based on Parameter Self-tuning Fuzzy Control

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Abstract. With the development of China's industry and the "Made in China" and "Created in China" proposals, the automotive industry has developed rapidly. Nowadays, China's car ownership and sales volume has ranked first in the world. The rapid growth of vehicle ownership has also brought problems such as traffic congestion and frequent accidents. Traffic accidents often bring double losses of human and financial resources. Rear-end collisions should be given a lot of attention as high-incidence traffic accidents. This paper is based on the research of auto-tuning fuzzy control of vehicle auto-tuning system. Based on the vehicle's sensors to obtain the optimal road surface slip rate and road peak adhesion coefficient, the driver's input signal is synthesized, and the parameter auto-tuning fuzzy control is applied to multiple. After the fuzzy input is inferred from the complex input, the fuzzy output is determined to obtain the determined output signal effect and speed limit on the motor. At the same time, the safety distance of the actual road is predicted based on the peak adhesion coefficient of the road surface to remind the driver to drive safely and maintain the distance. This system can not only remind the driver to drive safely with a safe distance, but also limit the speed of the vehicle itself to ensure the safe driving of small cars.

1. Introduction
Since the beginning of the 21st century, the proportion of vehicles in our country has been increasing. So far, China's car ownership and car sales have ranked first in the world[1]. Survey data show that, as of the end of 2019, there were 261.5 million civilian cars in the country, an increase of 8.1% year-on-year. Due to the huge vehicle base, the number of accidents and casualties is increasing significantly each year. The vigorous development of China's automobile industry has brought tremendous pressure on traffic safety[2]. Of these sudden accidents, rear-end collisions account for a large part. Therefore, countries all over the world attach great importance to automotive safety technology, especially the research on rear-end collision prevention systems[3]. In harsh weather conditions, especially in rainy days, snowy roads, ice conditions, etc. car rear-end collisions are particularly important. The anti-tailing system based on fuzzy control researched in this paper can automatically identify the road situation, and calculate the optimal slip rate and peak adhesion on this road according to the optimal slip rate and peak adhesion coefficient of the car on the standard road. Based on this, the fuzzy control theory is used to limit the speed of the motor, and the safe distance is determined based on the peak adhesion coefficient of the road surface. The vehicle rear-end collision prevention system based on fuzzy control has effective control effect, which can greatly improve the safety and stability of the vehicle on bad roads.
2. Overall design plan

The overall design of the system is shown in Figure 1. The slip rate calculation module calculates the real-time slip rate of the road surface according to the actual speed of the vehicle and the angular speed of the wheel rotation. The pavement recognition module calculates the optimal slip rate and the peak road adhesion coefficient based on the weights in the database according to the longitudinal acceleration of the wheel speed, the angular acceleration of the wheel, and the real-time slip rate. The parameter auto-tuning fuzzy controller performs fuzzy estimation based on the driver's input signal, optimal slip rate, peak attachment coefficient, and real-time slip rate, and finally outputs a certain signal to the motor and limits its speed. At the same time, the safety vehicle distance calculation module obtains and displays the predicted value of the safety vehicle distance on the actual road according to the vehicle speed and the road surface peak attachment coefficient.

Figure 1. Overall system block diagram

3. Obtaining the optimal slip rate and peak adhesion coefficient of the pavement

Slip means that the distance actually traveled by the drive wheels is less than the distance that should be traveled during pure rolling. The wheel slip rate is the ratio of the theoretical speed of the vehicle to the difference between the actual speed and the theoretical speed[4].

\[ S = \frac{\omega r - v}{\omega r} \]

\( \omega \): driving wheel angular velocity; \( r \): driving wheel rolling radius; \( v \): actual vehicle speed

The research on the slip rate can obtain the respective proportions of the wheels rolling and sliding during the running of the vehicle. Based on this, the driving state of the vehicle can be obtained, which has certain binding force on the determination of the safe distance.

The adhesion coefficient is the ratio of the adhesion force to the wheel normal pressure (direction perpendicular to the road surface). It is determined by the road surface and tires. The larger the coefficient, the greater the available adhesion and the less difficult the vehicle is to skid. After obtaining the road surface adhesion coefficient, the road type can be clearly determined, and the safe braking distance of the vehicle on different roads can be calculated to ensure the safety of the vehicle.

In order to accurately describe the functional relationship between the wheel slip ratio \( S \) of different road surfaces and the adhesion coefficient \( \mu \) between the tire and the road surface, after a large number of comparative calculations, the \( \mu - S \) function curve proposed by Burckhardt et al. Its expression as follows[5] (fitting coefficients are shown in Table 1):

\[ \mu(S) = C_1(1 - e^{-C_2 S}) - C_3 S \]
C₁, C₂, C₃: fitting coefficients

According to the actual situation, four typical representative pavements, dry asphalt, wet asphalt, snow, and ice, are selected here for fitting.

Table 1. Fitting coefficients on various road surfaces

| Road surface | C₁   | C₂   | C₃   |
|--------------|------|------|------|
| Dry asphalt  | 1.28 | 23.99| 0.52 |
| Wet asphalt  | 0.86 | 33.82| 0.35 |
| Snow         | 0.19 | 94.13| 0.06 |
| Ice          | 0.05 | 306.4| 0.001|

From this, the optimal slip rate \(S'_{\text{opt}}\) and peak adhesion coefficient \(\mu'_{\text{max}}\) of each of the four standard roads can be calculated according to the following formula:

\[
S'_{\text{opt}} = \frac{1}{C_2} \ln \frac{C_1 C_2}{C_3}
\]

\[
\mu'_{\text{max}} = C_1 + \frac{C_1}{C_2} (1 + \ln \frac{C_1 C_2}{C_3})
\]

Table 2. Optimal slip rate \(S'_{\text{opt}}\) and peak adhesion coefficient \(\mu'_{\text{max}}\) on various road surfaces

| Road surface | Dry asphalt | Wet asphalt | Snow | Ice |
|--------------|-------------|-------------|------|-----|
| \(S'_{\text{opt}}\) | 0.17 | 0.13 | 0.06 | 0.03 |
| \(\mu'_{\text{max}}\) | 1.17 | 0.80 | 0.19 | 0.05 |

Of course, roads are more complicated in practice and it is impossible to fully meet the four standard roads listed above. Therefore, after the vehicle-mounted road surface sensor obtains the real-time slip rate and adhesion coefficient according to the various states of the wheels, the road surface recognition module compares this real-time slip rate and adhesion coefficient with the data in the above four standard road surface databases to obtain the actual road surface conditions. The proportion of these four standard roads, and the corresponding weight coefficients are calculated. Then according to the weighted average formula of the optimal slip rate and the weighted average formula of the peak road adhesion coefficient, the optimal slip rate \(S_{\text{opt}}\) and the peak adhesion coefficient \(\mu_{\text{max}}\) of the actual road are calculated.

\[
S_{\text{opt}} = \sum x_i S'_{\text{opti}} + x_2 S'_{\text{opt2}} + x_3 S'_{\text{opt3}} + x_4 S'_{\text{opt4}}
\]

\[
\mu_{\text{max}} = \sum x_i \mu'_{\text{maxi}} + x_2 \mu'_{\text{max2}} + x_3 \mu'_{\text{max3}} + x_4 \mu'_{\text{max4}}
\]

\(x_i\): the degree of similarity between the actual road surface and the standard road surface

4. Determination of motor speed limit and safety distance

4.1. Motor speed limit

Because of the need to integrate factors such as slip rate, adhesion coefficient, driver input, and many intermediate variables to achieve the final speed limit and maintain safe distance, it is too complicated and difficult to accurately control this system with traditional control theory. The use of fuzzy control theory can simplify the complexity of system design, and it is easy to control and master the ideal non-linear controller, which has better robustness, adaptability and fault tolerance[6].
This paper uses the parameter self-tuning fuzzy control theory, as shown in Figure 2. The real-time slip rate, optimal slip rate, peak attachment coefficient, and driver input through the control device are calculated by various vehicle-mounted sensors and converted to the value of the discourse in appropriate proportions. They are described using spoken variables. And then find the relative membership of the value based on the appropriate language value. Then, based on the relevant definitions and language control rules for processing fuzzy data in the knowledge base, fuzzy logic and fuzzy reasoning are used to make inferences, and corresponding fuzzy control signals are obtained. Finally, the fuzzy value obtained from the inference is converted into a clear control signal as the input value of the motor, and the speed is limited.

4.2. Determination of safety distance
The acquisition of the safe distance is determined based on the vehicle speed and the peak adhesion coefficient of the road surface. Under the same road conditions, the road surface adhesion coefficient is the same, and the corresponding safety distances at different vehicle speeds are shown in Table 2. The higher the speed, the greater the safety distance for driving.

Table 3. Safe distances at different speeds

| Speed          | <20km/h | <40km/h | 50km/h | >60km/h | >100km/h |
|----------------|---------|---------|--------|---------|----------|
| Safety distance| 15      | 30      | 60     | 100     | 200      |

Under different road conditions, the adhesion coefficient of each road is different. Assuming that the vehicle is traveling at a speed of 60km / h, the driver will react and complete the braking operation in 1.5s after seeing the situation. Comprehensively analyze the various factors that affect the safe driving distance, and use the following simple and feasible formulas to calculate[7]:

\[ d = vt + 9\ln \frac{v^2}{\mu_{\text{max}}} \]

\( d \): safe distance; \( v \): vehicle speed; \( t \): driver response time; \( \mu_{\text{max}} \): Pavement peak adhesion coefficient

The calculation of the safe vehicle distance on different roads is shown in Table 3. It can be seen that when the dry asphalt and wet asphalt are the same under other conditions, the safe vehicle distance is not much different, and the snow road and ice surface are safer than the dry asphalt and wet asphalt. The distance is much larger. It can be seen that the smaller the adhesion coefficient, the greater the safety distance that the vehicle should maintain during driving.

Table 4. Safe distances on different roads

| Road surface | Dry asphalt | Wet asphalt | Snow  | Ice   |
|--------------|-------------|-------------|-------|-------|
| \( \mu'_{\text{max}} \) | 1.17        | 0.80        | 0.19  | 0.05  |
| Safety distance | 73.36      | 77.73       | 90.21 | 102.69 |
In real life, the situation on the road is complex and changeable, so various data obtained by the on-board sensors often change. Parameter self-tuning fuzzy control has strong adaptability to changes in the environment, and can automatically correct the controller in a random environment, so that the system can maintain a good performance even when the characteristics of the controlled object changes or there is a disturbance[8].

5. Conclusion
This paper studies that vehicle anti-follower system can obtain parameters such as road peak attachment coefficient and optimal slip rate, and the parameter self-tuning fuzzy control method can be used to fuzzily and infer multiple and complex inputs. The conditions of different road conditions and the driver's control input result in a clear output signal that acts on the motor and controls the rotation of the motor to play a role of speed limit. This control method not only has strong adaptability to the environment, but also can automatically adjust the controller in a random environment. In addition, on the basis of the peak adhesion coefficient of the road, the safe distance to be maintained on the actual road is calculated based on the speed of the vehicle, and the safe distance is displayed to remind the driver to keep the vehicle distance. With the dual guarantees of motor speed limit and safety distance, the vehicle can stop braking before the rear-end collision accident of the small car, ensuring the safe driving of the small car[9].

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