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Active fault-tolerant control and performance simulation of electric vehicle suspension based on improved algorithms

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Abstract

Based on the semi-active suspension controller of an automobile, the control law can be adjusted based on the control law reorganization idea, and the active fault-tolerant controller of the semi-active suspension is designed to make the fault closed loop system and the fault-free suspension semi-active suspension. Active suspension closed-loop systems have the same closed-loop pole or proximity system performance. Bench test and simulation results show that: the fault suspension under the control of the active fault-tolerant controller lags behind its performance level after some time and can quickly recover to the same performance as the fault-free automotive semi-active suspension level. And the simulation test and bench test results are basically consistent. Based on the concept of control law reorganization to design the active fault-tolerant control strategy of semi-active suspension, it can effectively realize the active fault-tolerant control of the semi-active suspension of the vehicle to improve the suspension control quality and reliability, and optimize the suspension design.

Keywords: PSO, Multiple degrees of freedom, Vehicle model, Active suspension, Robust control

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1. Introduction

After comparative studies, electric vehicles driven by electric wheels have obvious advantages in the structure of the chassis, transmission efficiency, power performance, and continued course [1]. However, it compared with a concentrated motor-driven electric vehicle, the electric wheel vehicle rigidly connects the hub motor and the wheel, and the quality of the hub motor directly constitutes the unsprung mass of the entire vehicle, which significantly increases the unsprung mass of the vehicle, and will inevitably lead to vehicles [2]. The deterioration of the vertical dynamic performance, the reduction of ride comfort, and the increase of the dynamic load of the wheels are an important problem affecting the promotion of such electric vehicles [3]. Some scholars have conducted some researches on the root cause and delivery route of the vertical negative effect [4]. Considering that the suspension acts as an important way to transfer the forces and moments acting between the wheel and the frame, the performance of the suspension will directly affect the smoothness of the electric wheeled vehicle. However, the parameters of the passive suspension are fixed and cannot effectively solve the problem that the unsprung mass increase leads to a then decrease in vehicle ride comfort [5]. As far as the current level of technology and scientific research are concerned, the innovative electric wheel technology still matches the passive suspension system. Therefore, the development of non-traditional types of intelligent suspension (semi-active suspension and active suspension) for electric wheel vehicles must be implemented that will become a research hotspot with the virtual prototype of a multi-function electric wheel was established [6]. Such an electric wheel design saves chassis space and makes the entire vehicle mechanical structure more compact. Based on the above research, this article will further discuss the semi-active suspension control strategy that is matched with the electric wheel so as to realize the purpose of integrating the semi-active suspension in the hub to improve the smoothness of the vehicle [7]. These factors are intertwined with each other in the driving process of the general vehicle and act on the vehicle comprehensively, and the matching characteristics between the various factors directly affect the effective cooperation of each system. Through analysis, the key factors affecting operational stability are determined, and the coordination relationship between these factors is accurately grasped, which can provide a theoretical basis for improving the stability of vehicle operation [8].

Focuses on the study the operating stability influence factors, the coordination between the not give the full consideration to the road, the road test data collected all contains road impact factor, the influence of the road surface excitation was isolated able to accurately determine the vehicle provide theoretical basis for the synergy between various agencies [9]. The influence of poor road surface on stability is not negligible. In the vehicle vibration model, the front wheel and rear wheel can be approximately the spring; as the front suspension and rear suspension can be approximated by the parallel of spring and damping [10]. The driver's seat can be approximately parallel to the spring and the damping. In order to ensure that the front and rear wheels can traverse the road surface elevation equally, the time delay is set according to the vehicle speed, and the typical road surface excitation is simulated and analyzed in the Simulink [11]. By analyzing the vehicle yaw rate, lateral force, and the lateral and lateral deviation angles of the vehicle under the pulse input road surface and the random input, the effects of different signal amplitudes and signal powers on the stability of the vehicle are determined. Therefore, the following aspects should be considered and enhanced [12].

1) Seat and passenger have a great influence on the vibration of the car. This directly affects ride comfort.

2) The correlation between the left and right wheels and the lag between the front and rear wheels cannot be ignored.

In order to verify the practicability of this mathematical model, the frequency response function from the input of the front wheel road surface roughness displacement input to the seat vibration acceleration is established using the MATLAB software programming language, and the rear wheel road surface roughness displacement input is input into the powertrain pitch angle vibration displacement [13]. Inter-frequency response function and simultaneously, and the time domain response of the pitch angle of the vehicle body and the powertrain, Model as show in figure 1.

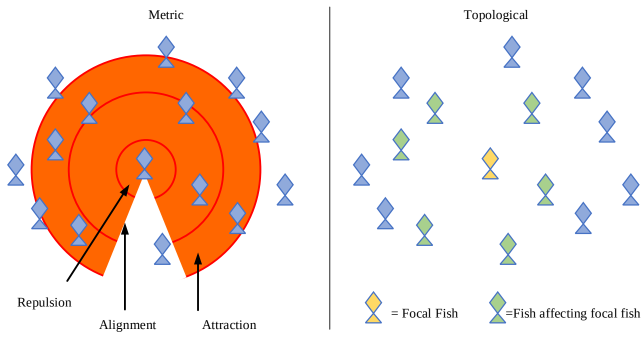

Fig. 1 The Model Considered

The new electric wheel is coupled with other parts of the electric vehicle, which forms a four-wheel independently driven electric wheel vehicle. The four hub motors are coaxially mounted in four wheels. The onboard power supply uses a lithium battery [14-15]. The battery supplies power to the motor. The energy is transmitted through the inverter, and finally to the motor controller. Finally, the entire vehicle is completed by four electric wheels drive. The electric wheel car is basically symmetrical in the space structure, the suspension mass distribution coefficient can be approximately equal to 1, and the mathematical model of a two-degree-of-freedom quarter vehicle can well represent the basic elements of the semi-active suspension design [16].

In the actual application of the controller designed by the traditional method, performance is often difficult to achieve the original design requirements, and even make the system unstable. Considering the uncertainty of the vehicle speed and tire cornering stiffness introduced by changes in the driving conditions and road conditions of the vehicle, the rear wheel steering is determined by the steering of the front wheels and the state of the vehicle [17]. In this paper, a two-degree-of-freedom robust four-wheel steering controller for a vehicle is designed using a robust control theory, namely a feed-forward controller plus a feedback controller and compared with a conventional zero-offset angle controller.

2. Active Suspension Control of Vehicle Model Based on PSO

2.1. PSO

By particle swarm optimization algorithm. The cooperation between individuals can be strengthened, and the optimal solution can be obtained through information sharing and data exchange. Based on the principle of particle swarm optimization algorithm and the actual situation of the relevant control system of electric vehicles, this paper constructs the structural model as shown in Figure 2.

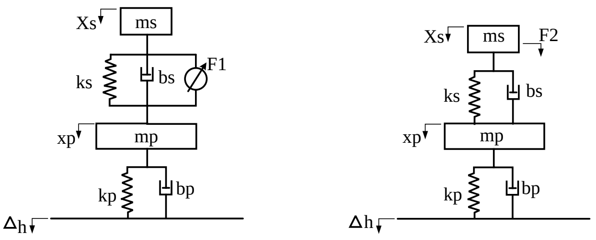

Fig. 2 The Structure Modelling

2.2. Parametric analysis and settings

Group size N: generally take 20 to 40, for difficult or specific types of problems can be taken to 100 to 200.
Maximum speed Vmax: Determines the resolution (or precision) of the area between the current position and the best position. If it is too fast, the particle may go over the minimum point; if it is too slow, the particle cannot explore enough outside the local minimum point, and it will fall into the local extremum area. This limitation can achieve the purpose of preventing calculation overflow and determining the granularity of the problem space search.
Parameter settings:
1) If c1=c2=0, the particle will always fly at the current speed until the boundary. It is difficult to find the optimal solution.
2) If =0, the speed depends only on the current position and the best position in history. The speed itself has no memory. Suppose a particle is in the global best position, it will remain stationary, and other particles will fly to the weighted center of its best position and global best position. The particles will shrink to the current global best position. After adding the first part, the particles have a tendency to expand the search space, which also makes the effect of adjusting the balance of the algorithm's global and local search capabilities for different search problems. When it is larger, it has a stronger global search capability; when it is smaller, it has a stronger local search capability.
3) Usually set c1=c2=2. Suganthan's experiments show that when c1 and c2 are constants, a good solution can be obtained, but it does not have to be equal to 2. Clerc introduces a constriction factor K to guarantee convergence.

3. Active Fault-Tolerant Control Design

The trouble-free automotive semi-active suspension is controlled by the LQG controller for good control. When the gain change fault of the actuator occurs, the LQG controller designed under no fault condition will not achieve the desired control effect. The semi-active suspension of a car has reduced performance and deteriorated reliability. Based on the Robust observer's estimated output and the actual output of the semi-active suspension system, the residuals of the system output are obtained, and the residual is used as the signal to design a semi-active suspension fault detection system to detect the moment of fault occurrence. The output residuals and control inputs are used as signals to design a semi-active suspension on-line diagnostic system to diagnose actuator fault gains online in real time and then based on the control law reorganization ideas and diagnostic information to achieve active fault-tolerant controller design. The active fault-tolerant control decision-making mechanism will switch between the LQG controller and the active fault-tolerant controller based on the results of fault detection and diagnostic information, and implement active fault-tolerant control of the fault suspension so that it still has good ride comfort, or has no fault The performance of automotive semi-active suspensions is close to that of the control, improving control reliability. The Optimized Structure Control as show in figure 3.

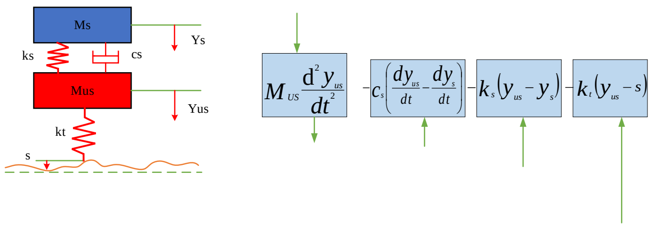

Fig. 3 The Optimized Structure Control

The control law reorganization is that after the automobile semi-active suspension actuator fails, it is not necessary to change the structure of the LQG controller of the semi-active suspension of the vehicle, but only to adjust the parameters or gain matrix of the original LQG controller according to the fault detection and diagnosis results. Automatically corrects controller gain, compensates for faulty actuator output, and improves suspension smoothness. Since the control law reorganization does not require changing the controller structure, it is easier to implement the project than the control law reconstruction method that requires changing both the controller structure and the controller parameters. Moreover, for the damping-adjustable 2 degree-of-freedom semi-active suspension with 1/4 vehicle, there is the advantage of adjusting the adjustable damping force to compensate for the malfunctioning actuator output. If the vehicle suspension is to be reorganized using a control law, the control force can be re-allocated among the four actuators. No matter what type of the active suspension, effective and reliable control algorithms are needed. Only a perfectly designed control system can achieve the superior performance of the active suspension. Therefore, the active suspension control research has always been a very active field, and the results achieved are also outstanding. The Simulated Data as show in figure 4.

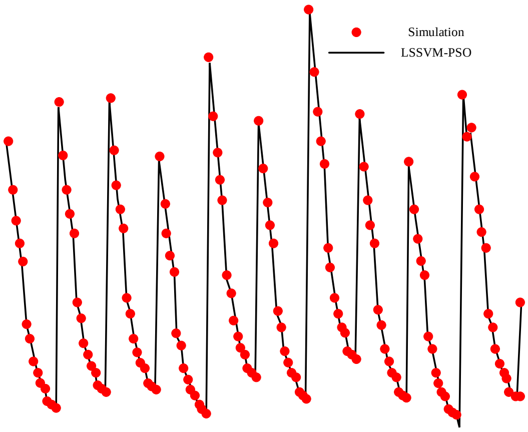

Fig. 4 The Simulated Data

According to the theory of modal exhaust system of suspension position should be on the vibration node, but different order vibration mode, vibration node change is very big, so the exhaust hanging position is not a simple arrangement on vibration node; In the practical engineering application, the placement of the suspension position is also restricted by the vehicle chassis space. Therefore, the hanging position arrangement is one of the objectives of exhaust system design. The road will produce a lot of bumps in the driving process of the car. If it is directly transmitted to the occupant, it will bring a very uncomfortable experience to the human body. Therefore, a transition tool is needed to reduce the vibration. The suspension of a vehicle is such a transition tool. The effect of the bearing in suspension is to reduce the friction caused by the rotation of the front wheel and bear the load of the front axle of the car. Therefore, we should understand the following aspects.

1) Adaptive studies how to change or generate auxiliary signal controller parameters to keep them as close as possible to specified performance metrics and optima.

2) The intelligent control is simply to adjust the situation of the automobile suspension according to the situation of the road surface, and reduce the manual intervention as much as possible, so as to strengthen the real-time performance of the data.

The semi-active suspension system matched with the electric wheel is a typical non-linear uncertain system. It is difficult to obtain the accurate model of the system due to external environmental disturbances, modeling errors, and changes in vehicle parameters. Most control strategies of the suspension require the control object to have an accurate model. Therefore, even if a robust fuzzy control strategy is adopted, when the parameters of the suspension model change, the control system performance will decline or even lose stability. Robust control can effectively suppress interference and is a powerful tool for dealing with uncertainties. In the process of establishing the mathematical model and controller design process, the influence of uncertainty can be fully taken into account, so that the control system can meet the desired performance indicators. It can also ensure the robust stability of the control system. Therefore, the application of robust control in the field of intelligent suspension control for automobiles has received extensive attention. Both theoretical analysis and actual vehicle experiments have fully demonstrated the robust control theory. It is the superiority of frequency domain theory in the design of semi-active suspension systems. The following will study the control strategy for semi-active suspension of electric wheel vehicles based on robust control.

The body vibration acceleration, suspension dynamic travel and tire dynamic displacement are the three main evaluation indicators for general evaluating vehicle ride comfort, but the requirements of ride comfort on these three indicators are often contradictory and mutually restrictive, for example, tire grounding improvement will cause The increase in the suspension stroke will also lead to an increase in the amplitude of the body's vibration acceleration in the high-frequency range, thereby reducing the ride comfort; in order to improve ride comfort, it can be achieved by reducing the body vibration acceleration, but this will imply that the suspension stroke increase. In addition, from the viewpoint of vehicle handling stability, the tire cannot leave the ground, but it is not expected that the dynamic displacement of the tire will be too small. In order to coordinate the output of each evaluation, the control output is weighted according to relative importance, and a robust weighted transfer function matrix is introduced.

4. Conclusion

Based on the semi-active suspension controller of an automobile, the control law can be adjusted based on the control law reorganization idea, and the active fault-tolerant controller of the semi-active suspension is designed to make the fault closed loop system and the fault-free suspension semi-active suspension. Active suspension closed-loop systems have the same closed-loop pole or proximity system performance. Bench test and simulation results show that: the fault suspension under the control of the active fault-tolerant controller lags behind its performance level after some time and can quickly recover to the same performance as the fault-free automotive semi-active suspension level. And the simulation test and bench test results are basically consistent. Based on the concept of control law reorganization to design the active fault-tolerant control strategy of semi-active suspension, it can effectively realize the active fault-tolerant control of the semi-active suspension of the vehicle to improve the suspension control quality and reliability, and optimize the suspension design.

Considering that the suspension acts as an important way to transfer the forces and moments acting between the wheel and the frame, the performance of the suspension will directly affect the smoothness of the electric wheeled vehicle. In order to verify the practicability of this mathematical model, the frequency response function from the input of the front wheel road surface roughness displacement input to the seat vibration acceleration is established using the MATLAB software programming language, and the rear wheel road surface roughness displacement input is input into the powertrain pitch angle vibration displacement. Inter-frequency response function and simultaneously, the SIMULINK platform is used to simulate the time-domain response of the basic seat, the center of mass of the vehicle body, the vertical acceleration of the center of mass of the powertrain, and the time domain response of the pitch angle of the vehicle body and the powertrain. Bench test and simulation results show that: the fault suspension under the control of the active fault-tolerant controller lags behind its performance level after some time and can quickly recover to the same performance as the fault-free automotive semi-active suspension level.

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