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Technical study of magnetorheological semi-active suspension control strategy for vehicles based on reinforcement learning

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Abstract. The suspension system is an important part of the car, the main function is to alleviate the road surface does not level brought about by the shake, to ensure that the vehicle driving smoothness and comfort, so as to improve the vehicle handling performance and safety, improve the vehicle to reduce the vibration performance more and more become a hot topic in the industry. Among them, semi-active suspension is a popular suspension system. This paper explains the significance and classification of the role of the suspension, and gives a relevant introduction to the magnetorheological fluid, on the basis of which it combines the domestic and international research results, looks forward to the development trend of the semi-active suspension of the vehicle, analyzes the advantages and shortcomings of four important semi-active suspension control strategies, and finally introduces the reinforcement learning and combines the reinforcement learning with the existing control strategies of the semi-active suspension, and designs a reliable reward function to enhance the suspension's damping performance by taking into account the multifaceted driving factors. The reward function to enhance the damping ability of the suspension by considering multiple driving factors, which can provide a reference for further research on the control of magnetorheological semi-active suspensions for vehicles.

Keywords: Semi-active suspension, Reinforcement learning, Control strategies.

1. Introduction

1.1. The role and significance of automobile suspension

With China's rapid economic development, as of the end of 2023, China's car ownership has exceeded 300 million, sales and ownership for many years ranked first in the world, the vehicle market has also gradually changed from an incremental market to a stock market [1]. People's quality requirements for automobiles are also increasing, starting from the presence or absence of vehicles, turning more and more concerned about the comfort of the car. Automotive suspension system is a key component connecting the body and wheels, it plays a vital role in the vehicle driving process, it can not only stabilize the vehicle posture, resist the impact of braking, cornering and gusts of wind and other external forces, but also effectively absorb the impact of road surface unevenness, to enhance the comfort of the ride. At the same time, the design of the suspension system ensures that the vehicle in a variety of road conditions can maintain good handling and flexibility, to avoid excessive movement of

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the suspension system due to the hard stop or impact, thus comprehensively guaranteeing the safety of driving and ride comfort, and many studies have confirmed that prolonged exposure to high-intensity vibration will cause significant harm to the human body, especially the lumbar spine, spine and kidneys and other parts, they are more vulnerable to this type of vibration. They are more susceptible to this kind of vibration [2]. Therefore, suspension performance has a significant impact on the passenger and driver experience.

1.2. The development trend of automobile suspension

Automobile as a combination of mechanical manufacturing, electronic processing, artificial intelligence field, with the rapid development of artificial intelligence in recent years, the suspension system of the car is also rapidly developing in the direction of intelligent integration. Suspension can be divided into passive suspension, semi-active suspension and active suspension according to the control mode. Passive suspension has greater limitations because its damping size cannot be adjusted with the rapid changes in the actual situation, and it can only achieve the best performance in a specific state, which largely limits the development of intelligent integration of the suspension system. Active suspension can quickly adjust the stiffness of the spring for different situations, so as to maximize the possibility of guaranteeing the smoothness of automobile driving, but the active suspension needs to occupy a very large space, consuming too much vehicle energy, and therefore in the large-scale promotion of the application of the limitations. Therefore, in order to improve the overall performance of the suspension system and bring a more comfortable experience for drivers and passengers, while avoiding excessive volume and energy consumption, adjustable damping semi-active suspension came into being, which has the advantages of low price, simple structure and low energy consumption [3]. However, the semi-active suspension cannot be optimized and upgraded by itself to fit the current state of the automobile, so many scholars began to propose a control strategy to optimize the semi-active suspension, and its control strategy has gone through a lot of changes from the earliest classical control strategy to the modern control strategy and then to the intelligent control strategy, which will be described in details in the following section.

1.3. Several future issues to be addressed in magnetorheological semi-active suspension technology

In 1948, Rabinow created a new type of controllable fluid by adding materials, which is considered as the early form of magnetorheological fluid (MRF). Magnetorheological fluids with reversible rheological properties, low energy consumption and fast response characteristics are key materials for the development of smart controllable magnetorheological dampers (MRD) [1]. However, the magnetorheological semi-active suspension system poses a great challenge to its popularization and application due to its significant nonlinear characteristics and time-lag uncertainty. Among them, the time-lag characteristics have a critical impact on the frequency response range and control stability of magnetorheological dampers. In our pursuit of high comfort and stability, how to reduce the response delay of the magnetorheological damper by optimizing the structural design, or how to study and implement more effective magnetorheological semi-active suspension control algorithms to reduce the effect of time lag to ensure the stability of the system have become the core challenges to be solved in the process of magnetorheological semi-active suspension system design and development.

1.4. Summary of this chapter

This paper introduces the vehicle suspension system at the same time, will be combined with the latest research results at home and abroad on the vehicle's semi-active suspension and control strategy overview, and then explore the development trend of magnetorheological semi-active suspension technology, for the development of vehicle magnetorheological semi-active suspension control technology to provide support for the automotive industry in the hope of promoting the development of higher performance, better comfort and safer driving experience direction.

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2. Theoretical research

2.1. Classification of vehicle suspension and current research status

According to the different kinds of automobile suspension controlled and whether the motion mode is adjustable, the suspension is roughly divided into three categories: passive suspension, active suspension, semi-active suspension.

Passive suspension has been used in vehicles for the longest time, with simple structure and stable performance, its damping parameters and stiffness are designed empirically, and the rear fixation cannot be adjusted [4]. However, under the combined influence of the operating environment, the damping performance of the suspension cannot be fully utilized, and therefore the riding experience cannot be effectively guaranteed.

Unlike passive suspensions, active suspensions have external active adjustable element inputs, which make active responses according to the comprehensive influencing factors of vehicle operation, balancing with external excitation, and unlike passive suspensions, they take into account the ride comfort and maneuvering stability of the vehicle, so that the vehicle is in the state of optimal performance of damping [1]. However, the energy consumption ratio of active suspension is too large, and additional space is needed to install instruments, so it is difficult to realize in the large-scale promotion.

Semi-active suspension in 1973 by the University of California, Davis, Crosby and Karnopp proposed the concept of semi-active suspension, the use of external passive adjustable element input. Not only can it obtain good vibration damping performance, but also occupies significantly less space and mass, and has a higher cost-effective. However, the semi-active suspension adopts a fixed operation mode ("signal acquisition - algorithm calculation - current output"), which makes it difficult to optimize and update the control strategy in a timely manner when the vehicle is shipped from the factory, and thus it faces the challenge of decreasing vibration damping effect with the life cycle. In addition, when the traditional control strategy is applied to the semi-active suspension, it faces high hysteresis, which makes it difficult to give full play to the system efficiency. Accordingly, it is necessary to optimize the control strategy of the semi-active suspension to further improve the comfort of vehicle operation.

2.2. Working principle of magnetorheological semi-active suspension and current research status

In 1948, Rabinow created a new type of controllable fluid by incorporating fine soft magnetic particles in the carrier fluid and adding auxiliary materials, which is regarded as the early form of magnetorheological fluid (MRF).When no external magnetic field is applied, the damping effect is very close to that of a conventional damping fluid. However, when an external magnetic field is applied, its damping coefficient is significantly enhanced. Within a certain range of magnetic field strength, the magnetorheological fluid can produce a large yield stress under a small magnetic field, and its damping coefficient is closely related to the magnetic field strength. Magnetorheological fluids are mainly used as key materials for the development of intelligent controllable magnetorheological dampers (MRDs) due to their excellent reversible rheological properties, low energy consumption and fast response characteristics.

The most important component of magnetorheological semi-active suspension is magnetorheological damper, MRD is mainly a new type of damper filled by magnetorheological fluid, under the restriction of the damper, the characteristics of magnetorheological fluid can be changed by controlling the current and voltage to influence the electric field strength, which can then control the output of MRD and the desired damping force [2]. At present, foreign research on MRD is more advanced, the most representative is the U.S. LORD company, the first MRD successfully used in automotive suspension damping [5]; domestic although the start time is late, but in the major universities and research institutes of unremitting efforts, also produced certain results, such as East China Jiaotong University of Hu Guoliang, etc., for the impact of the environment on the MRD, the design of a new type of energy recyclable MRD, but there is still a long way to go before commercialization [5].

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In summary, a large number of research results have made magnetorheological technology more and more mature, and MRDs have been widely used in vibration damping devices of various types of vehicles by virtue of the advantages of rapid response, small size, simple structure, low energy consumption, continuously adjustable damping force, high stability, and so on [4].

2.3. Research progress of magnetorheological semi-active suspension control strategy

Magnetorheological semi-active suspension has similar vibration damping ability as passive suspension, and the output damping force can be adjusted according to the real-time changes of road surface and vehicle conditions, and it does not need to input a large amount of energy. However, guaranteeing the best performance of magnetorheological semi-active suspension largely depends on the semi-active suspension control strategy. Many researches have been done at home and abroad to solve this problem. This paper will introduce several typical semi-active suspension control strategies.

2.3.1. Classical control. Its main principle is to use the set algorithm, so that the damper can output the appropriate damping force, its operation is simple and convenient, can reduce the uneven road conditions brought about by the vehicle vibration problems, in order to increase the smoothness of vehicle driving, improve the vehicle ride experience, but the damping coefficient of the damper switching discontinuous, the adaptability of the changes in the vehicle is poor, and can not achieve the desired results [1].

2.3.2. PID control. Proportional Integral Differential (PID) because of its working principle is relatively simple, in the engineering is extremely widely used, but a single use of PID control parameter calibration is very difficult, in practice, most of them are to take the empirical value, can't solve the nonlinear problem, so at present generally PID control and other control strategies combined, can further improve the performance of the magnetorheological semi-active suspension [2].

2.3.3. Optimal control. Optimal control is to find the minimum performance index to meet the state equation of the system, using modern control theory to construct a mathematical model [4].Optimal control theory can be generally divided into three categories: $H\infty$ control, linear control, forecast control. Among them, linear-quadratic control was firstly applied to the field of automobile suspension. It has been found that compared with some traditional control, optimal control has better effect in improving body stability and improving the experience of riding.

2.3.4. Fuzzy control. In the field of intelligent control fuzzy control is used quite widely, its most important feature is that it does not need the mathematical model of the controlled object as well as a strong ability to deal with nonlinear systems [5], as we all know, the vehicle in the process of driving the semi-active suspension system has a strong uncertainty and complexity, based on these reasons the use of fuzzy control real-time adjustment of the output damping force, generally in combination with the PID control-use.

3. Reinforcement Learning

3.1. Overview of reinforcement learning

Reinforcement learning is a machine learning method of learning to make decisions by interacting with the environment, which was first proposed in 1954, where an intelligent body selects actions in a specific state and adjusts its strategy according to the reward feedback it receives to maximize long-term gains [6]. It has made great progress in recent years in both theory and practical applications, and it is widely used in games, robot control, autonomous driving, etc. The core concepts include intelligence, environments, states, actions, rewards, and strategies.

Simply put, for the known familiar environment, after a certain amount of training, reinforcement learning using algorithms for each choice to make the optimal control; for the unknown unfamiliar

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environment, reinforcement learning will first be the unpredictable input situation for the equal probability of choosing the output, we set the performance index for evaluating the reinforcement learning system as a, choose which makes the performance index a maximum, then the choice is the optimal solution for the current situation. However, in practice, because the performance metric is affected by many aspects, in order to get more accurate selection decisions, the performance metric is often determined by the reward function, which is affected by the main factors of multiple decisions.

3.2. Current Research Status of Reinforcement Learning

Reinforcement learning has a fairly wide range of applications, with involvement in various fields, but what makes reinforcement learning enter the public's field of vision is that Alpha Go beat Ke Jie, the world's top-ranked player at that time, on the Go Summit in 2017, and it is the algorithm of reinforcement learning that is utilized by Alpha Go.

In addition, reinforcement learning can be a line of psychological behaviorism theory, imitating the human brain to learn [7]. With the maximum reward function as the expected goal of learning, the intelligent body and the environment stimulate each other, constantly interact, and constantly improve and optimize its own learning strategy, which makes reinforcement learning better than the traditional automotive semi-active suspension control strategy. After a series of research, reinforcement learning has achieved results in vehicle suspension strategies.

3.3. Semi-active suspension strategy optimization based on reinforcement learning

Currently, in order to reduce the dependence of the semi-active suspension control strategy on the accuracy of the mathematical model, we can still maintain good damping effect under different inputs, i.e., to maintain a good driving experience of the car under different road conditions. We incorporate reinforcement learning as a way to optimize our existing algorithms for more stable and accurate decision making, but designing an effective reward function is the key, and even more difficult, to achieve excellent performance.

In this paper, we briefly discuss three aspects, firstly, the overall comfort of the vehicle, i.e., the smoothness of the acceleration, we can use the standard deviation of the acceleration as part of the reward, the smaller the standard deviation, the higher the reward, comfort=f(a), where f(a) is the standard deviation of the acceleration; and then the stability of the vehicle, i.e., the sway angle, we can use the magnitude of the sway angle as part of the reward, the smaller the sway angle, the higher the reward, the higher the reward, the higher the reward. The smaller the angle, the higher the reward, stability =θ, where θ is the angle of the vehicle's lateral inclination; finally, the overall energy consumption of the semi-active suspension, i.e., the frequency of the damping adjustment of the semi-active suspension, can be used to use the magnitude of the adjusting frequency as a part of the reward, and the lower the adjusting frequency is, the higher the reward is, energy=f, where f is the frequency of the damping adjustment. For these three major aspects, we can multiply them by different weighting coefficients according to the actual vehicle conditions and actual needs, and then make a comprehensive evaluation to get a more accurate reward function.

In addition, multiple aspects such as vehicle dynamic response, road surface adaptability, passenger comfort, vehicle safety, maintenance cost and environmental impact can be considered comprehensively, and a more comprehensive and effective reward function can be designed. This will make the semi-active suspension control strategy based on reinforcement learning perform better under different road and driving conditions, and improve the overall driving experience and safety.

4. Conclusion

With the continuous improvement of people's living standards, improving vehicle ride comfort has been a popular topic of vehicle research in the past few years. Suspension system not only has an impact on the maneuverability and safety of the vehicle, but also has a significant impact on the ride comfort and extends the service life of the vehicle, so it is evident that a good suspension system plays a key role in the development of transportation in the city, while the vehicle driving on the road is

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unpredictable, so the semi-active suspension control strategy based on reinforcement learning has become one of the directions to improve the ride comfort of the vehicle.

In this paper, on the basis of introducing the current research status of vehicle semi-active suspension, we analyze the working principle of magnetorheological fluid and magnetorheological semi-active suspension, expound the current research status at home and abroad, and also review the control strategies of magnetorheological semi-active suspension, but the traditional control strategies rely too much on the accurate mathematical model and cannot be optimized by themselves over time, and each of them has certain defects. Therefore, this paper focuses on the analysis of the semi-active suspension control strategy combined with reinforcement learning, through the construction of an accurate reward function for the vehicle suspension vibration damping performance has been further improved, reducing the impact of different road surfaces on the suspension vibration damping performance, so as to satisfy people's requirements for vehicle ride comfort.

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