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Review on the development and optimization of steering systems for autonomous vehicles

Jiayi Liu

Beijing Jiaotong University, School of Mechanical, Electronic and Control Engineering, Beijing, China, 100091

19222010@bjtu.edu.cn

Abstract. The steering system of an automobile is an extremely important part. The development of unmanned driving technology has put forward new requirements for the steering system. This paper summarizes the three mainstream steering systems in the market, combines them with the requirements of automatic driving technology, and compares and analyses their strengths and disadvantages. The optimal solution of a steering system in the field of automatic driving is given, and research on the development of steering systems in the future is focused. The conclusion is that hydraulic steering system is not suitable for the use of autonomous vehicles. At present, most autonomous vehicles use EPS, but EPS has limitations. The steer-by-wire system under research will be widely used in the field of autonomous driving in the future.

Keywords: Steering System, Steer by Wire, Automatic Drive, Electric Power Steering, Hydraulic Power Steering.

1. Introduction

At present, with the progress of electronic information technology, the application of new electronic technology in the automobile industry advances by leaps and bounds. The development of new technologies for automobiles and parts has just become an important platform for the application of these new technologies [1].

By comparing the characteristics, advantages, and disadvantages of the three steering systems, this paper refers to the requirements of automatic driving on the steering system function. Which system is more suitable for automatic driving is analyzed, and an optimal design is selected for the steering system of automatic driving. Finally, the future development of steering systems is prospected.

This paper introduces the development history of steering systems and gives people a preliminary understanding of the three main steering systems and their characteristics and adaptability. This paper has guiding significance for automobile manufacturers to choose the proper steering system.

2. The traditional steering system represented by hydraulic assist

Hydraulic power steering systems were studied early, as early as 1953, when General Motors used hydraulic power steering systems (HPS) for the first time. The system is based on the original mechanical steering system to add a hydraulic assist device, and the use of engine-driven steering oil pump to help, thereby reducing the driver's operating torque, saving physical strength, and improving

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steering lightness. Due to the reduced volume of the steering system, the power consumption is reduced [2].

HPS is generally composed of steering tank, steering tubing, power cylinder and mechanical device, and hydraulic power steering system can help. But in the system, after the design parameters are determined, the performance of the power steering system is determined; the power characteristics cannot be adjusted with the actual situation; and steering lightness and road sense are difficult to coordinate. And when the engine is working, regardless of whether there is a steering problem, the steering oil pump has been working normally, and the energy consumption is large. Therefore, it is not suitable for the new era of intelligent self-driving cars [3].

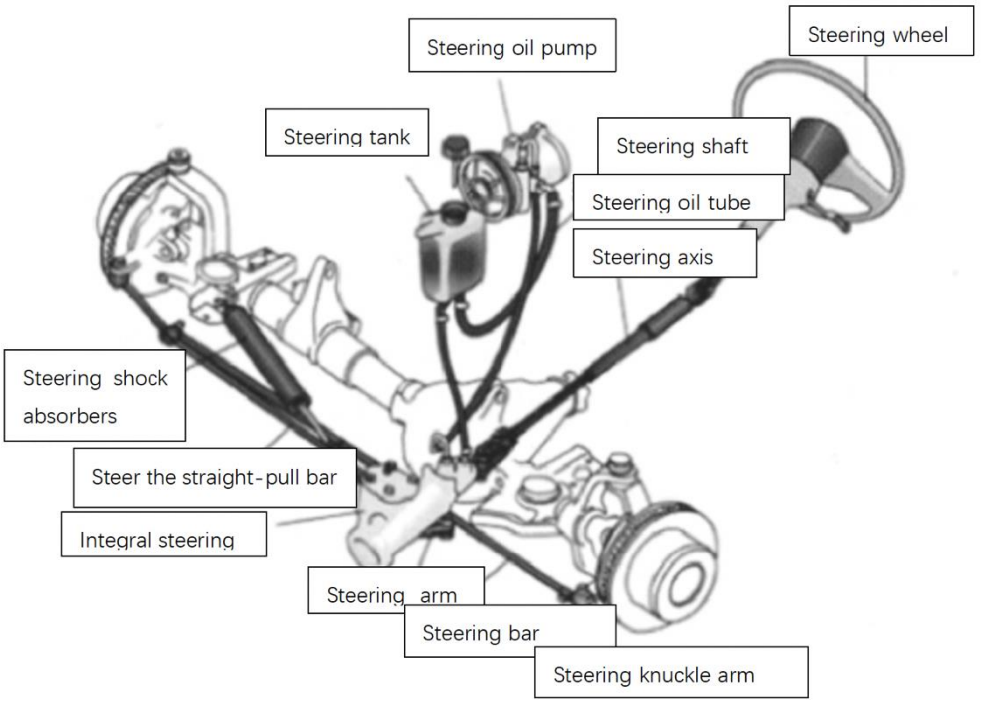

Figure 1. Hydraulic system structure diagram [4].

3. The electric power assisted steering system (EPS)

The electric power assisted steering system (EPS) uses the power of the motor as the power source and uses the electronic control device to exert the auxiliary force on the steering transmission mechanism to assist the driver to operate and realize the steering power.

EPS can provide optimal steering assistance according to the driver's steering wheel input torque and vehicle speed, making the car's steering more portable and reducing the driver's handling burden. With the booming development of autonomous driving technology and 5G communication technology, EPS can also be used as the steering actuator of autonomous vehicles to complete the seamless connection with autonomous vehicles. By designing an excellent active steering control algorithm, EPS output steering torque to realize real-time and accurate tracking of target position, and complete active steering.

Figure 2 shows the schematic diagram of electric power steering system.

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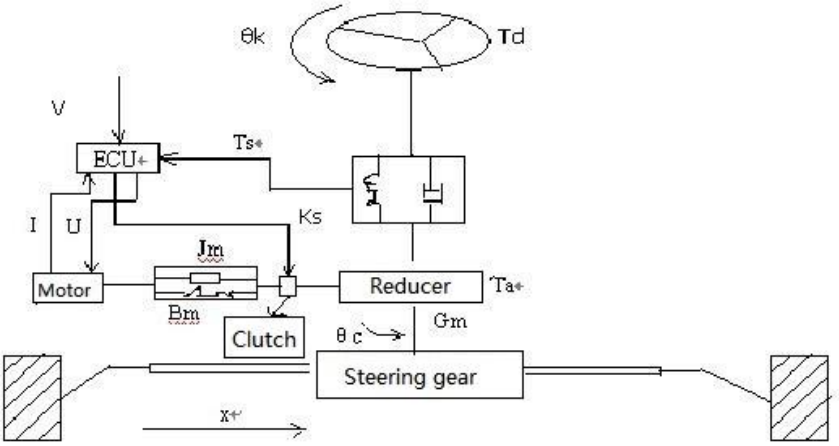

Figure 2. Schematic diagram of electric power steering system [5].

3.1. Control method of EPS system

About the control method of EPS system, the main application at home and abroad is PID control, fuzzy control, and H∞ control three methods [6].

3.1.1. PID control in power assisted control mode. PID control is the most widely used control method in continuous system. Advantages are simple structure, good stability, reliable work.

There is no need to understand the mathematical model of the controlled object, only need to adjust the control parameters online according to experience [6].

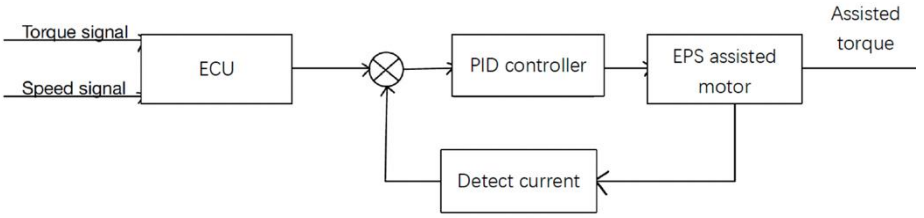

Figure 3. Structure diagram based on PID control [6].

3.1.2. Fuzzy control in power assisted control mode. With the increase of complexity, nonlinearity, and coupling of the controlled object, the possibility of using traditional precise control is decreasing. Fuzzy control is based on fuzzy set theory and fuzzy logic reasoning. It converts the knowledge and control experience expressed in natural language into a mathematical model through fuzzy theory and then uses a computer to process it. It is an intelligent control [6].

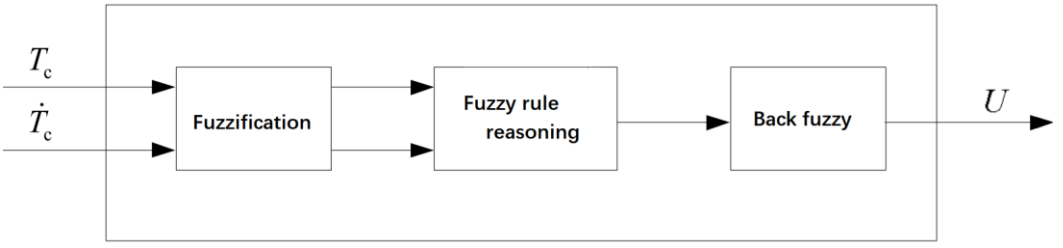

Figure 4. Schematic diagram of fuzzy controller [6].

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Fig.4 is the schematic diagram of the fuzzy controller. According to the measured value of the torque sensor and its change rate, the control voltage of the booster motor is obtained through fuzzification, fuzzy reasoning, and de-fuzzification of the fuzzy controller.

3.1.3. H∞ control in assisted control mode. In practical engineering applications, some systems will have serious nonlinearity, PID control and fuzzy control are not applicable. To minimize the impact of disturbances on the system, H∞ control is introduced. For the generalized control system as shown in FIG6 [6]:

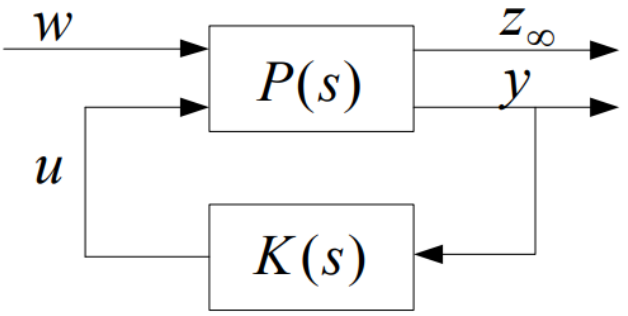

Figure 5. H∞ Control standard construction [6].

P(s) is a linear time-invariant system, and the standard state-space model is described as follows.

$$\begin{cases} \dot{x} = Ax + B_1 w + B_2 u \\ z = C_1 x + D_{11} w + D_{12} u \\ y = C_2 x + D_{21} w + D_{22} u \end{cases} \tag{1}$$

$$p(s) = \begin{bmatrix} P_{11}(s) & P_{12}(s) \\ P_{21}(s) & P_{22}(s) \end{bmatrix} = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{12} & D_{22} \end{bmatrix} \tag{2}$$

The closed-loop transfer function from the external input W to Z is

$$T_{zw}(s) = P_{11}(s) + P_{12}(s)K(s)\left(I - P_{22}(s)K(s)\right)^{-1}P_{21}(s) \tag{3}$$

Comprehensive of the advantages and disadvantages of the three methods, the preferred method of EPS system control is PID control. If you have experience and research time, fuzzy control is also a good method, and when compared to PID control, the system reaction time is shorter, and the system is more sensitive. If serious nonlinearity exists in the system, H∞ control is chosen.With the development of electronic and sensor technology, the cost of hardware has decreased significantly, and the EPS system itself has many advantages.

Advantages, major auto manufacturers will continue to research and develop the EPS system and its supporting components. Future research directions.

It mainly focuses on improving the output power of the EPS steering motor and improving the steering road sense of the EPS system, so that it can be used in automatic driving cars [6].

4. Steer-by-wire system

The existing steer-by-wire systems can be divided into two categories: front-wheel steer-by-wire systems and distributed steer-by-wire systems. This paper gives an example of wheel-by-wire steering system.

Figure 6 is a schematic diagram of Steering by wire system of the front wheel.

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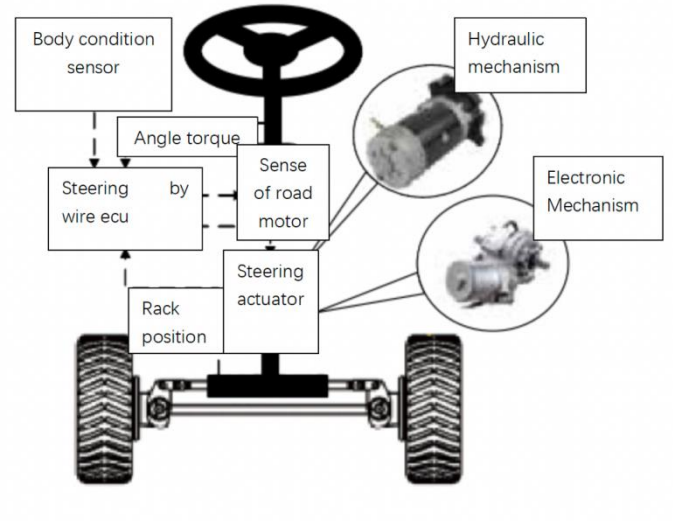

Figure 6. Steering by wire system of the front wheel [7].

4.1. Road sense control of steer-by-wire system

Road sense control of steer-by-wire system usually consists of two parts. The first is road sense planning, which is how to design the steering wheel feedback torque to reflect the current real-time road sense through theoretical modeling analysis. The second is road sense tracking control, which is how to control the torque output of the road sense motor through the electronic control unit based on the planned road sense (steering wheel feedback torque) [8].

4.2. Stability control of steer-by-wire system

Compared with the traditional mechanical steering system, the main advantage of the steer-by-wire system is that it can complete the complete decoupling of the force transfer and displacement transfer of the steering system. In short, the force transfer characteristics and displacement transfer characteristics of the steering system can be designed independently [7].

1) Stability control of steer-by-wire, that is, which reference model is selected through the driver's input to complete the control of the vehicle's stability and displacement characteristics.

2) The design of the variable transmission ratio of a steer-by-wire system is to obtain the corresponding relationship between the driver's corner input and the front wheel's corner output according to what rules.

3) The tracking problem of front wheel Angle, that is, how to control the output torque of steering motor to track the reference value on the premise of knowing the reference front wheel Angle.

4.3. Control of steer-by-wire system for intelligent vehicles

The steering system by wire control motor through the electronic control unit to control the direction of the vehicle, can complete the active steering and automatic steering functions, to achieve assisted driving, parallel driving, and even automatic driving, by adjusting the control weight between the driver and the steering system controller, not only according to the driving habits of different drivers, driving characteristics, and the current driving situation of the vehicle, to provide personalized driving assistance, but also to help drivers gradually adapt to the transition from auxiliary driving to automatic driving. It is the best choice for intelligent car steering system [7].

4.4. The challenges ahead

Under autonomous driving conditions, especially in complex road conditions and driving environments, it is necessary to plan a safe path and achieve accurate and fast path tracking, while the existing control

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algorithms are not yet sufficient in terms of environmental adaptability, so the steer-by-wire system faces a series of challenges [7]:

A. Most of the existing mature steering execution control strategies only realize steering assist function, which cannot meet the requirements of offline steering execution control in an automatic driving environment. Especially for complex road conditions and traffic environments, it is necessary to develop adaptive and robust steer-by-wire execution algorithms [8].

B. The steer-by-wire system needs to be highly integrated and coordinated with other (sensing, chassis, power, etc.) automatic driving control subsystems. Complexity and reliability are challenges.

C. Drivers need to solve collaborative problem between intervention and control strategy of autopilot fusion.

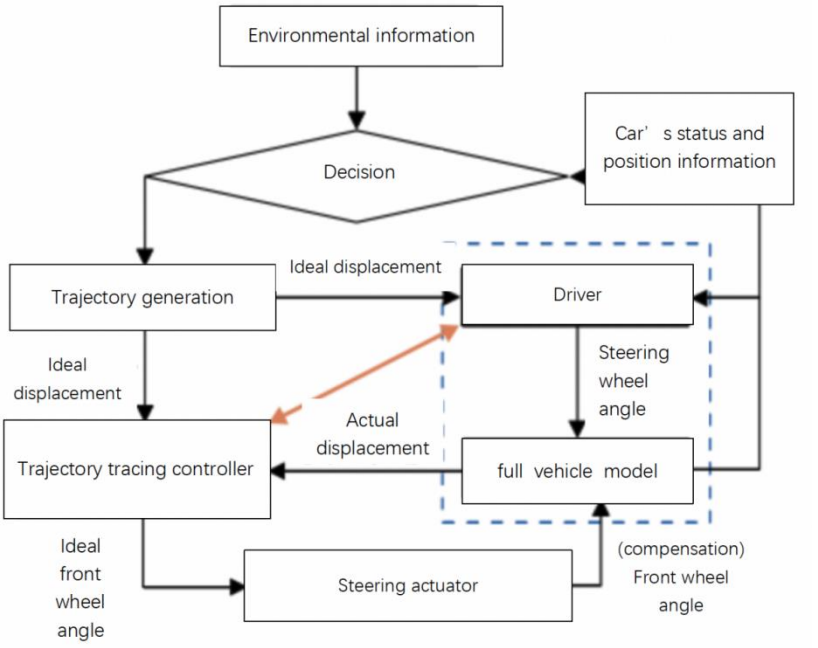

Figure 7. Steering-by-wire control flow for intelligent vehicles [7].

4.5. Prospects of steer-by-wire control technology

The intelligent drive-by-wire chassis system aims to achieve the goals of individual driving, assisted driving, and unmanned driving through drive-by-wire and intelligence, which is the key technology for the landing of intelligent connected vehicles. The steer-by-wire system, as an important part of the steer-by-wire chassis, should also move towards the same goal. To further promote the development of steer-by-wire technology, further research can be carried out in the following aspects [9].

a. The adaptability and robustness of the steer-by-wire steering system under complex road conditions and complex traffic environment conditions, and the ergonomics of different driving styles.

b. Failure mode and redundant fault tolerance control strategy under extreme working conditions.

c. Real vehicle loading and real vehicle performance verification of the prototype of the steering system by wire control system, laying the foundation for market promotion and application.

d. Considering the complex working conditions, the operation analysis and evaluation index of the steering system by wire control meets the good handling stability and the comfort of the vehicle driver and occupants [10].

5. Conclusion

This paper analyzes 3 steering systems.

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Because of its own advantages, EPS has gradually replaced other steering systems, but due to the problem of the actuator motor, its auxiliary power is much smaller than the hydraulic system, EPS is more widely used in cars, but heavy vehicles more commonly use hydraulic power systems. With the continuous update of modern intelligent transportation systems, electronic technology and new materials technology, higher requirements are put forward for EPS. Whether it is hardware development or software control strategy, the future EPS will have high reliability, low cost, and low energy consumption. From a single function to multifunctional change; the design and manufacture of EPS will be more modular and standardized. At present, new energy vehicles, such as pure electric vehicles, can use the motor with little power when choosing the EPS system, and the requirements for the maximum booster current and other indicators have decreased, because the use of the charging problem is still very limited. Hybrid electric vehicle adopts the EPS system.

The system can reduce fuel consumption by about 2%. Steer-by-wire, as the next generation of steering systems, will keep up with the pace of the times, overcome the reliability and safety problems in the future development, and be widely used.

In this paper, three kinds of steering systems are simply summarized and compared without specific experiments and simulations, which are accidental and limited. In the future, steering system experiments on real cars will be carried out to analyze the advantages and disadvantages of various steering systems and strive to obtain more suitable experimental data.

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