Analysis on the research method of road sense feedback in steer-by-wire system

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Abstract. Nowadays, the automobile industry is gradually developing towards the trend of electrification and intelligence. Compared with the traditional steering system, the steer-by-wire system cancels the mechanical transmission structure, reduces the space utilization, reduces the probability of damage to the driver caused by the steering system in the collision accident, and improves the driving portability and enhances the driver’s handling experience. The road feeling feedback of steer-by-wire system has the greatest impact on the driver’s driving experience. This paper discusses the research methods of road feeling feedback of steer-by-wire system, introduces the basic structure of road feeling feedback of steer-by-wire system, the basic idea of dynamic modeling, the establishment of simulation model of road feeling feedback, and the establishment method of control strategy and simulation platform of road feeling feedback. Finally, it summarizes and prospects in order to provide basic information and perspectives for the development and research of steer-by-wire system.

1. INTRODUCTION
At present, the rapid development of China’s economy and the rising voice of environmental protection have greatly promoted the development of new energy vehicles. With the development of new energy vehicles, the traditional mechanical structure can no longer meet the intelligent control requirements of new energy vehicles.

The steering-by-wire system has become a new generation of steering system, which cancels the mechanical connection between the steering wheel and the steering actuator and adopts the wire beam connection control. It reduces the use of the cab space, improves the angular transfer characteristics, improves the force transfer characteristics, and is conducive to communication and integration with other active control systems, and is the typical foundation for the realization of automobile autonomous steering[1]. The existing steering system is that the return torque generated by the tire is transmitted to the driver through the mechanical steering system, and the information transmitted to the driver also includes the road adhesion coefficient, road roughness, steering degree and tire pressure. The steer-by-wire system cancels the mechanical connection and cannot transmit the feedback torque through the mechanical structure. It is necessary to collect the data of the vehicle through the sensor, calculate the torque that can truly reflect the road feel, and transmit the torque to the driver through the simulation of the road feel motor, so that the driver can control the vehicle more accurately.

2. Brief introduction of road feeling feedback of steer-by-wire system
The steer-by-wire system is composed of steering wheel assembly, steering execution assembly and controller. In addition, there are fault diagnosis system, power supply system and other auxiliary systems.
The schematic diagram of steer-by-wire system structure is shown in Figure 1.

Figure 1. Structure diagram of steer-by-wire system

The steering wheel assembly collects steering wheel torque signal through torque sensor and angle sensor and converts it into electrical signal to transmit to ECU, so as to realize the control function of the lower steering executive assembly. At the same time, the torque signal transmitted by the ground is transmitted to the road sensor motor through the ECU. The road sensor motor simulates the actual road feeling, so that the driver can understand the real-time state of the vehicle and perceive the road information.

The steering executive assembly can receive the control signal from the ECU, and drive the steering mechanism to steer through the steering motor. At the same time, the information of the vehicle can be collected through the sensor and transmitted to the ECU for the generation of road feel signal to control the road feel motor.

ECU is the core part of the steer-by-wire system. The steering wheel transfer information, steering feedback motor and front wheel steering motor control are all completed. Moreover, with the development of science and technology, the scope of the role of ECU is also increasing. When the steering execution or steering feedback command is obtained, the main controller makes reasonable adjustments according to the vehicle driving state and road condition information to ensure the safety and stability of the vehicle in the driving process to the maximum extent.

For the control mode of steering feel feedback, it can be divided into three categories:

- Measurement method: The sensor is used to measure the return torque of the gear rack in the steering structure, and then the road induction motor is used to carry out the feedback torque of the simulator. However, this method requires high accuracy and high cost of the sensor.
- Fitting method: By establishing the functional relationship between the feedback torque and the relevant parameters, the size of the feedback torque is estimated.
- Dynamic model method: by combining a corner information, vehicle driving state, and according to the dynamic model of the vehicle to estimate the way out feel torque and compensation system inherent torque to obtain the desired feedback torque.

The dynamic model method is designed based on the dynamic model of the vehicle, and the final feedback torque combines the results of vehicle driving state and driver operation. Compared with other control methods, the estimation results of the dynamic model method are more accurate, so the most important control method is based on the vehicle dynamic model. The follow-up content of this paper mainly introduces the research method of road feeling feedback based on dynamic model.

3. Vehicle Dynamics Modeling
Before the simulation experiment, it is very important to establish the dynamic model of the steer-by-wire system to analyze the steering characteristics of the vehicle, which is related to the effectiveness of
the subsequent simulation experiments. The steering wheel dynamic model and vehicle lateral dynamic model need to be established for the linear control chassis system.

The parameters related to the steering wheel dynamic model include input torque, system inertia, road induction motor torque, damping and friction. The dynamic equation is as follows [3,4].

\[ \tau_{hw} = J_{hw}\ddot{\theta}_{hw} + B_{hw}\dot{\theta}_{hw} + K \left( \theta_{hw} - \theta_{m} \right) + f_{hw} \]  

(1)

\[ \tau_{m} = J_{m}\ddot{\theta}_{m} + B_{m}\dot{\theta}_{m} + \frac{K \left( \theta_{hw} - \theta_{m} \right)}{i_s} \]  

(2)

In the formula, \( \tau_{hw} \) is the steering wheel torque, \( \theta_{hw} \) is the steering wheel angle, \( J_{hw} \) steering wheel / motor inertia, \( B_{hw} \) steering wheel / motor damping coefficient, \( f_{hw} \) is the direction friction torque, \( \tau_{m} \) is the road induction motor torque, \( K \) torsional stiffness, \( \theta_{m} \) is the road induction motor angle, \( i_s \) is the deceleration ratio.

For vehicle lateral dynamics model, the following assumptions should be established [3]:

- It is considered that the characteristics of the left and right sides of the car are consistent, and the change of the return torque caused by the change of the left and right wheel load is ignored.
- Ignore the road and tire contact normal force on the tire during driving, and ignore the air friction resistance.
- It is considered that the left and right wheel angles of the vehicle are consistent when steering.

Based on the dynamic analysis of the vehicle, the longitudinal and lateral dynamic equations of the vehicle and the dynamic equations of the yaw direction obtained by the torque balance of the vehicle around the Z axis are established.

4. Road sense feedback control model

For the road inductance torque of the linear control chassis steering system, it can be divided into the upper return torque and the lower road inductance torque. The upper return torque controls the road-induction motor to return to the steering wheel quickly without external force through appropriate control algorithm. The lower layer can estimate the road feel moment by the estimation method of design parameters.

The torque dynamic equation of road sense feedback of steer by wire vehicle can be expressed by the following formula [5]:

\[ \tau = \tau_1 + \tau_2 \]  

(3)

\[ \tau_1 = J\ddot{\theta} + B\dot{\theta} + \tau_d \]  

(4)

\[ \tau_2 = \tau_{da} + \tau_{in} + K (\tau_{al} + \tau_{ja}) \]  

(5)

where, \( \tau_1 \) represents the upper return torque of the steering wheel, \( \tau_2 \) represents the lower road inductance torque, \( \theta \) represents the rotation angle of the steering wheel, \( B \) represents the viscous friction coefficient, \( J \) represents the rotational inertia of the steering wheel, \( \tau_d \) denotes motor torque disturbance, \( \tau_{da} \) and \( \tau_{in} \) represent the equivalent damping and inertia torque of the system, \( K \) represents the road inductance torque gain, \( \tau_{al} \) represents the sub return torque, and \( \tau_{ja} \) represents the lifting torque.

Through the above dynamic equation, the parameters in the formula can be further decomposed and analyzed in detail to obtain a model that can more accurately reflect the road feeling.

5. Road sense feedback control strategy

The control strategy of road sense feedback is shown in Figure 2.
Firstly, the rotation angle is input to the system, and the relevant information is transmitted to the steering wheel model and the vehicle dynamics model by combining the relevant parameters of the vehicle. The upper return torque and the lower road inductance torque are calculated by the corresponding algorithm, and then the road inductance torque is calculated. The corresponding information is transmitted to the road inductance motor, and the torque generated by the road inductance motor is fed back to the driver through the steering wheel.

For the calculation of the upper aligning torque, the common control strategy is PID control, which is close to the real algorithm by controlling the coefficients of proportional, integral and differential. The principle is simple, stable and reliable, but it is difficult to ensure the feedback transmission of the torque in the calculated response time domain. In the literature [6], the fuzzy algorithm is used to adjust the parameters, and the simulation results are better improved in response time and overshoot. In addition, it can be controlled by the traditional sliding mode control method, which has strong robustness to the dynamic change of model parameters and interference problems, and the algorithm design is simple. On this basis, [2] in the literature adopts the terminal sliding mode control algorithm, so that the calculation time can be controlled within a certain period of time, and the uncertainty of modeling parameters is considered. The influence of system uncertainty is eliminated, and the road information can be transmitted to the driver more accurately. In the follow-up study, the neural network algorithm can be considered to further optimize the upper torque algorithm. For the estimation of the lower road inductance torque, it is more difficult than the calculation of the upper aligning torque. It is necessary to reflect the real information of the road that the vehicle is driving. The dynamic characteristics of the tire sideslip, the tire lateral force and the change of the aerodynamic trajectory should be considered. The control strategy in Reference assumes that the sideslip angle is small, and some unknown parameters are estimated by the least square method. The parameters that are easy to obtain are used as far as possible to estimate, and the lower road inductance torque is obtained and fed back to the road inductance motor for output according to a certain gain.

6. **Road Feedback Simulation Platform**

The above contents include the establishment of dynamic model, the establishment of road feedback control model and the idea of road feedback control strategy. In the actual research process, the simulation research can be carried out after the above operations are completed.
The above contents include the establishment of dynamic model, the establishment of road feedback control model and the idea of road feedback control strategy. In the actual research process, the simulation research can be carried out after the above operations are completed. For the simulation of road feedback research, most of the literature used the method of Matlab / Simulink and CarSim co-simulation for research. The overall simulation platform structure diagram as shown in Figure 3:

![Figure 3. Structure of the overall simulation platform](image)

In the simulation, the Matlab / Simulink simulation is used to generate the corner signal and the signal is transmitted to CarSim, and then CarSim obtains the corner information. The simulation is carried out according to the set automobile model and environmental parameters, and the required parameters are transmitted to Matlab / Simulink in real time. Matlab / Simulink processes the data and controls the operation of the vehicle according to the parameters and the designed control algorithm.

After completing the above operation, the simulation results are evaluated and the optimization control algorithm is continuously analyzed to obtain better road feel feedback.

This method can make the simulation conform to the actual situation to the greatest extent, and can carry out real-time control of the vehicle model, obtain more accurate results, ensure safety and save costs.

7. **Conclusion**

With the continuous development of the automobile industry, the requirements for automobile chassis are also increasing. Intelligent lightweight chassis has become one of the directions of future development. The wire control chassis cancels the mechanical structure and uses the wire harness to control. While reducing the weight of the chassis, it can be more intelligent and lightweight, which meets the requirements of future development. At present, the development of steer-by-wire technology is still in the stage of continuous improvement, and some technologies need to be broken through. This paper introduces the basic structure of road feedback of steer-by-wire, the basic idea of dynamic modeling, the establishment of road feedback simulation model, and the establishment method of road feedback control strategy and simulation platform in order to provide basic research ideas for more researchers in the future. For the study of road sense feedback, it is still difficult to make more accurate dynamic modeling, and the ideal assumption of the model leads to the real state of the system cannot be obtained, which reduces the accuracy of feedback. At the same time, the research on the upper control algorithm can also be more in-depth. For example, the neural network method is used to design the control algorithm in order to obtain more realistic design results.

Some technical problems of the wire control system still need to be solved, and it is difficult to promote the application in large quantities on vehicles at this stage. However, it is believed that with the rapid development of new energy vehicles and automobile electronic technology, the problem of line control system will be gradually solved, and it will conform to the trend of the times and combine with intelligent Internet vehicles to become a new generation of chassis system.

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