Control strategy and simulation verification of hardware-in-the-loop system of automotive steering device

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Abstract. As one of the key technologies of intelligent assisted driving simulation, hardware-in-the-loop control system has gradually become the focus of attention. Driverless has gradually become a hot topic. This paper designs a hardware-in-the-loop system of the steering device, that is, the steering device and the software system form a closed loop. This paper studies two control strategies including manual driving and driverless driving. This hardware-in-the-loop system is designed by the upper computer and controlled by the lower computer. The communication between the steering wheel and the upper computer is realized through the serial communication protocol. This hardware-in-the-loop system can simulate two modes of manual driving and driverless driving, and a visual interface is made on the display screen, which can effectively analyse the steering in real time. It provides a basic platform for the research of automobile steering and driverless driving.

1. Introduction
Hardware-in-the-loop simulation combines the advantages of physical simulation and digital simulation. The hardware-in-the-loop is the hardware in the loop. It is a hybrid simulation of software and hardware. Some actual hardware is connected to computer simulation software through computer software. Software and hardware coordinate with each other to perform real-time dynamic simulation [1]. It connects a part of the instruments and equipment of the hardware system to the computer, and uses software modeling to simulate the parts that are difficult to perform the actual test. The steering operation has a great influence on the safety and durability of the car, and the hardware-in-the-loop platform can easily perform repeatable experiments, can quickly modify the vehicle parameters, integrate the dynamic parameters, and facilitate the inspection of their functions and performance. And diagnostic behavior, so in theory the hardware-in-the-loop system is perfectly repeatable for experiments [2]. Hardware-in-the-loop simulation makes perfect use of the convenient characteristics of computer modeling. Through the simulation results of the hardware-in-the-loop simulation system, we can verify the reliability of the system. The hardware-in-the-loop simulation makes the experimental premise closer to the actual situation. It can debug and test the control system, develop the control system and reduce the number of field tests, so it can effectively save costs.

Luo Chuandong established a lane departure warning experiment using a hardware-in-the-loop system, and established an I/O interface model in Simulink to realize the connection between software and hardware CAN signals. The working state of lane departure warning system was studied.
Research shows that HiL technology can solve the actual vehicle testing process. It faces complex and difficult problems, such as poor repeatability of working conditions [3]. Amir Soltani of Francis Assdian et al. Analyzed and considered the loop model (MiL), loop software (SiL), loop processor (PiL) and loop hardware (HiL). They built an integrated active steering and brake HiL system and verified the brakes accordingly. The system can be used for early verification of production systems in [4].

When building a hardware-in-the-loop platform, many authors use Carsim to provide vehicle models and scenarios to set and simulate vehicle parameters [5-8]. Wu Di and others use a real car driving simulator as the steering wheel module of the steering by wire system. The software part includes monitoring software and simulation software. CarSimRT is used as simulation software. The software provides the vehicle model and simulation environment for the system. Matlab / Simulink is used to write control algorithms to achieve software control. Finally, the author chose to change the speed of the snake-shaped working conditions to verify the test bench in [5]. In their respective articles, Liu Yanlin and Cong Guanghao set the vehicle parameters, road surface parameters, etc. in Carsim to conduct hardware-in-the-loop experiments, and implemented the control using C language [6,7]. Wu Shengbo and other authors use the linear quadratic regulator trajectory tracking control algorithm to set the vehicle shape and vehicle dynamics parameters in Carsim, build a simulation model in Matlab, and finally use real vehicles for verification [8].

In the hardware-in-the-loop system, many authors use Matlab / Simulink as the software control part in [5,8-11], and some authors use other languages [6-7,10]. The software part of the hardware-in-the-loop system is composed of VC ++ and Matlab. VC ++ performs control and uses Matlab BP neural network for training. Through this system, the driverless steering control can be analyzed online [10]. Huang Qi and others studied the automatic steering control of unmanned vehicles. which based on Matlab to achieve control and simulation, through the adjustment and control of the vehicle model to achieve the steering wheel speed and rotation angle adjustment [11].

There are many ways to implement communication between software and hardware [3,9,10,12-14]. Sun Rongqiang and others used the vehicle dynamics model of the vehicle dynamics software veDYNA to provide vehicle models and road scenes with integrated steering and braking systems, and designed the control module with Simulink. Real-time communication in [12]. The semi-physical simulation system built by Zou Yimin and other authors uses the ADAM module to build a field interface, and uses serial communication function blocks in Simulink to achieve software and hardware communication [9]. Magalhaes and other authors use MiL and HiL to set and simulate vehicle dynamics parameters. HiL is connected to the analog-to-digital converter and Ethernet to run real-time simulations in the Real-Time environment to verify the nonlinear model introduced in the article [14].

The hardware-in-the-loop platform is used for various experiments [10,13-19]. Hao Liang and other authors designed the automotive ABS control and verified it using hardware-in-the-loop experiments [15]. Tavernini, D. Vacca et al. Used hardware-in-the-loop verification of the ABS electrohydraulic brake system controller [16]. Hardware-in-the-loop simulation designed by Delgado de Melo et al. Including data expansion, power system simulation, verification, data visualization and processing. Finally, the author compares the simulation value in RSCAD with the device measurement value to verify the measurement process [17]. Meng Qingjian and other authors designed the electric power steering measurement and control platform. The power characteristics of the designed control strategy are realized on the workbench in advance, so as to realize the performance verification of the EPS system in advance. Finally, actual vehicle verification can effectively shorten the development cycle and reduce research costs. The test environment of the console uses LabVIEW. The hardware signal distribution part uses a data acquisition card and a CAN communication card. The test bench collects the steering wheel angle and torque through the data acquisition module, inputs it to the DYNA Ware model, and finally outputs the steering resistance torque, and displays the relationship curve in real time [13]. In [18], Michael Milford mentions car safety in the article. In order to further improve the safety of the car, it is difficult to achieve a limited number to prove the safety of the
vehicle under normal conditions, so simulation is very important. In [19], CJ Nash, DJ Cole mainly studies the relationship between driver’s senses and car steering, the author adopted Driving simulator experiment to obtain steering control behavior. In [14], Magalhaes and others use MiL and HiL to set and simulate vehicle dynamics parameters. HiL is connected to the analog-to-digital converter and Ethernet to run real-time simulation in the Real-Time environment to verify the nonlinear model.

This paper studies the steering wheel hardware-in-the-loop system, which includes two control strategies: manual driving and unmanned driving. The system connects the upper computer and the lower computer through the serial port, and analyses the steering signal of the steering wheel in real time.

2. Principle of Hardware-in-the-loop simulation system for steering

In the test system, we need to consider vehicle dynamics, sensor systems, road conditions, and other highly integrated control systems that are closely related to the test system. To develop an experimental platform, we need to perform a lot of tests to verify its feasibility. Considering that the actual vehicle testing as a general method requires a lot of cost and long time, the flexibility of the test is relatively poor, and there are still certain risks. Therefore, it is very important and necessary to develop a hardware-in-the-loop experimental platform. If the hardware-in-the-loop simulation technology is applied to the development of the steering wheel hardware bench test system in this paper, it will not only greatly reduce the development cost required for the product, but also greatly shorten the product development cycle. According to the structural composition of the steering wheel steering test system and the required performance requirements, a semi-physical simulation test bench for steering wheels was used. Combined with vehicle dynamics simulation software system control, an integrated hardware-in-the-loop system platform was developed.

The Hardware-in-the-loop simulation system of the steering device adopts two control strategies of driverless and driver’s manual turning of the steering wheel. Figure 1 shows the principle of simulation system. The steering wheel angle is transmitted to the lower computer with a CAN signal. After the lower computer reads, recognizes and processes the information, it sends the steering wheel angle to the upper computer through serial communication. The upper computer reads and processes the signal, which is transformed into a virtual scene. At the same time, the steering wheel angle of the vehicle model realizes the combination of the virtual scene and the actual scene to communicate with each other. Conversely, in the unmanned mode, the host computer converts the path that has been planned for the vehicle model in the scene into the steering wheel angle, and sends it to the steering wheel through the lower computer to make the steering wheel rotate the corresponding angle.

![Figure 1. Principle of Simulation System.](image-url)

Figure 2 shows the data transmission process. We divide this data transfer system into three main parts: a data input layer, a data processing layer, and a data output layer. Taking unmanned driving as an example, we will set up the built scene, vehicle dynamics parameters and road information, and
then input them into the simulation system. The input information is processed through software and the slave computer control module, and finally the steering wheel angle is output.

![Diagram showing data transmission process](image)

**Figure 2.** Hardware-in-the-loop simulation system data transmission process.

3. **Vehicle behaviour modelling**

3.1. *A subsection vehicle behaviour analysis*

Comprehensively consider two control strategies of the vehicle: manual driving and driverless driving. In order to realize accurate simulation and make the control operation experiment more meaningful, this paper needs to analyze the behavior of the vehicle. Figure 3 shows vehicle behaviour modelling. Vehicle behavior usually includes vehicle motion behavior and vehicle communication behavior, such as speed, acceleration, and position. When analyzing manual driving control strategies, vehicle behavior should focus on vehicle motion behavior, including speed, acceleration, and acceleration. Lane changes. This requires us to fully consider driving conditions that are close to actual conditions when constructing transportation infrastructure. We use the GUI interface in PreScan to build scenes, including intersections, traffic lights, roundabouts, etc. When analyzing the driverless driving control strategy, we plan the path for the vehicle model to make the vehicle follow the prescribed path. The key technologies of unmanned vehicles mainly include environment awareness technology and path planning and tracking technology. Path tracking is to complete the steering action under a predetermined path, and at the same time, it must pay attention to the safety, comfort and stability [20]. Only install sensors that are reasonably suitable for driverless vehicles, so that the vehicle can obtain real-time surrounding information, and then control the strategy so that the vehicle can meet pedestrians and the front when encountering obstacles (such as vehicles), you can slow down or park at a safe distance inside. At this time, the sensor data is transmitted to the communication model after analysis, so that the steering wheel can be controlled to make corresponding actions in real time to ensure the safety of driverless driving.

![Diagram showing vehicle behaviours](image)

**Figure 3.** Vehicle behaviour modelling.
3.2. Vehicle behaviour modelling
Firstly, in the Gui interface of PreScan, there are two test scenarios of manual driving and driverless driving, and vehicle dynamic models and visual sensors are added to the test vehicle. In the 3-D viewer in PreScan, we can observe the 3D renderings of the scene, infrastructure and vehicles. Set up the scene based on the menu form of PreScan, including road design, car selection, sensor matching, etc. The figure shows the 3-D Viewer, which shows the driver's perspective and the three-dimensional view of the completed model.

4. Control module construction

4.1. Simulink control model
The vehicle dynamics module controls the virtual vehicle, including the steering wheel angle, speed, etc. of the virtual vehicle. We output the vehicle speed and steering wheel angle in the trajectory tracking module to the vehicle dynamics module, and the virtual car will follow a predetermined path and speed. The communication module connects the software system and the hardware system, and stores, reads and processes the signal transmission between the two. In unmanned mode, we output the steering wheel angle signal in the vehicle dynamics model to the serial port, and realize the real-time control of the steering wheel angle of the platform through the communication module. In manual driving mode, the operator can control the virtual car model on the display by controlling the steering wheel actuator. Therefore, a combination of physical objects of the virtual vehicle and the steering wheel is realized.

For the Simulink model of the manual driving control strategy, in the vehicle module we can see the real-time position information, initial speed and final speed of the vehicle. We can set the initial speed and final speed. We set the real-time speed and throttle of the car. The degree and braking pressure are transmitted to the vehicle dynamics model in order to set a speed for the vehicle in advance. Because this paper studies the hardware-in-the-loop system control of automobile steering gear, the steering wheel angle in the vehicle dynamics model is the main part of our control model. We connect the software and hardware to each other through a USB to RS232 serial cable, so we need to add a serial receiver module and set the serial number, baud rate, and data bits. In order to limit the limits of the two directions of the steering wheel and the steering direction of the steering wheel is consistent with the operator's operating direction, we have added gains. We also added an oscilloscope to verify in real time whether the steering wheel angle and direction are consistent with the driver's operation. For the Simulink of the driverless control module, we must consider both the similarities and the differences between the two when designing. Driverless driving needs to set the path for the vehicle model first so that the vehicle can drive along the planned route itself, we set an S-bend for the car to make it easier to observe the correctness and accuracy of the steering wheel angle.

4.2. Lower computer design
In the design of the lower computer, we selected the XS128 microcontroller as the core board, the MCP4822 chip as the direction control module, and a voltage value corresponding to different steering wheel angles. The 82C250 chip was used as the CAN communication module to read and transmit CAN signals. The MAX232 chip was used to achieve the upper level Communication between the computer and the lower computer. At the same time, we need to add the Serial module to the software control Simulink of the host computer, and directly transmit the signal read by the serial to the vehicle dynamics model.

5. Hardware-in-the-loop test system
For our HiL test platform system, HiL testing plays a key role. The hardware-in-the-loop test is used to establish the association between the virtual real-time vehicle and the physical steering wheel actuator. This association can be used to verify the functionality of the HiL platform system. Figure 4 shows HiL test in manual driving mode, and Figure 5 shows HiL test in driverless driving mode.
There are two factors that affect the hardware-in-the-loop test: one is the communication between the steering wheel and the lower computer, and the other is the establishment of communication between the virtual scene and the actuator. For hardware-in-the-loop testing, the accuracy of the simulation model is the main factor affecting the test.

In order to test the usability of the hardware-in-the-loop system of the steering device constructed this time, we need to test it. The test system includes two modes: unmanned driving and manual driving. For the manual driving mode, we use a serial port debugging module to test whether the host computer reads the steering wheel signal. For the unmanned driving mode, we set the amount of turn signal that changes with time in Simulink to detect whether the steering wheel is turning. In order to detect whether the hardware-in-the-loop system has a disconnection failure.

![Figure 4. Hardware-in-the-loop in manual driving mode.](image)

![Figure 5. Hardware-in-the-loop in driverless driving mode.](image)

6. Summary
In order to verify the feasibility of the hardware-in-the-loop simulation platform and the accuracy of the simulation experiment, this experiment selected multiple paths from the scene modeling for the simulation experiment. The results show that the constructed hardware-in-the-loop simulation platform has sufficient accuracy to successfully recognize the hardware controller instructions and complete the manipulation experiments on virtual objects, and can also output the steering angle of the virtual object in real time.

The combination of hardware controllers and virtual control objects used in the hardware-in-the-loop simulation platform makes up for the disadvantages of pure hardware simulation (which is expensive) and pure software simulation (which is not reliable). On the basis of PreScan / Simulink, a hardware-in-the-loop simulation platform was developed and designed, making full use of flexible scene modeling features. It provides a variety of scene environment options for the experiment, and the actual test is more realistic. Technical research experiments provide reliable and convenient help.

The hardware-in-the-loop simulation platform has simple operation, good real-time performance and high reliability. In addition, the platform is based on an intelligent networking platform, which can quickly obtain and feedback environmental information and vehicle information through various sensors. The experiment platform can not only flexibly adjust the modeling and control strategy in real time according to the needs, but also can greatly save the funds required for the experiment and shorten the experiment period. However, the disadvantage is that due to the simulation frequency of the simulation system and the setting of the lower computer, the rotation frequency of the steering wheel and the dynamic display on the display in the loop system of the hardware are not smooth enough.

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