

Research Article

The Design for Hardware in the Loop Simulation Test Bench

Li Hui, Chen Hao*, Wang Yunchao, Lu Changyu

College of Automotive Engineering, Shanghai University of Engineering Science, Shanghai201620, China

***Corresponding author**

Chen Hao

Email: pschenhao@163.com

Abstract: HIL (Hardware in the loop) simulation test bench was developed based on the CarSim and LabVIEW software. First of all, CarSim, Real-time vehicle dynamics software, was used to build parameterized model for vehicle. Secondly, HIL simulation system, including vehicle steering wheel Angle, accelerator, brake, gear physical signals, was established based on the LabVIEW RT which was the real-time simulation environment of LabVIEW. And the steering wheel Angle sensor signal, throttle brake pedal sensor signal, gear sensor signal was introduced into the vehicle dynamics model through the hardware interface. Finally, the lemniscate road simulation test was used to verify the validity of the HIL simulation test platform. Lemniscate road simulation test included driver model simulation test and driver's practical operation HIL simulation test.

Keywords: CarSim, LabVIEW, HIL, Dynamics Simulation.

INTRODUCTION

HIL (hardware-in-the-loop) was a kind of typical semi-physical simulation method, it was compared with traditional real vehicle road test, it used simulation technology to simulate the actual working conditions of the original copy of the under test without being limited by the space and time and so on, it could be controlled and recycled quick test according to the specific purpose. Relative to the virtual simulation, it used the original physical replace the key parts which had a great influence on measure accuracy and real-time performance in the system model and black box parts which was difficult to accurately model, thus it could greatly improve the accuracy of the simulation test[1-3].

In this paper, HIL simulation test bench was developed based on CarSim and LabVIEW. CarSim RT, the vehicle dynamics simulation software for real-time simulation, was widely used in vehicle dynamics analysis, advanced vehicle control strategy development, HIL simulation and so on. LabVIEW [4-5], a graphical programming software, was developed by NI (National Instruments) company. It was widely used in industrial control, test and measurement, etc. LabVIEW RT, a module of LabVIEW, was specifically designed for real-time application development in the field of hardware and software architecture. In this paper, CarSim was used to set up the vehicle parameterized model, LabVIEW was used to write data acquisition program. Refer to the test requirements of steering portability of national standard of auto industry; lemniscate road simulation test was used to

verify the validity of the HIL simulation test platform. Lemniscate road simulation test included driver model simulation test and driver's practical operation HIL simulation test.

HIL SIMULATION TEST BENCH DESIGN

System configuration

As shown in figure 1, hardware in the loop simulation test bench [6-7] was mainly composed of upper machine, lower machine, the interface system, actuators and sensors. In the upper machine, vehicle parameterized model was set up by CarSim, data acquisition program was written by LabVIEW software. Lower machine was mainly provided a real-time operating system to implement the real-time operation of the vehicle model. Interface system obtained control object signal of the hardware system by sensors and input it to the vehicle model.

Carsim and LabVIEW were installed in the upper machine. CarSim was used to set up the vehicle virtual scene and the parameterized dynamic model. In the HIL simulation test, the driver can observe the real-time operation of vehicle. LabVIEW software was used to write data acquisition program, and the IP address of the lower machine was set in the upper machine. Vehicle parameterized model and data acquisition program were deployed to the lower machine by the Ethernet cable. The lower machine was used to simulate the working condition of the vehicle actual movement. The operator was used to observe real-time movements of vehicle model in the upper machine, and control the

vehicle model of steering, braking, forward and backward and so on through the hardware system in real-time. Lower machine adopted the IPC-610-L Advantech industrial computer, communicated with the upper machine by the TCP/IP protocol. Interface system used B series multi-function data acquisition card PCI-6010 of NI (National Instruments) company to measure the analog signals and digital signals. In the

lower machine, the acquisition card communicated with the real-time system through PCI bus. Steering wheel Angle sensor, accelerator pedal sensor, brake pedal sensor and gear sensor were included. Actuators included steering wheel, throttle brake pedal and the gear. In the running process of real-time system, actuators and sensors communicated with the whole vehicle model mainly by interface system.

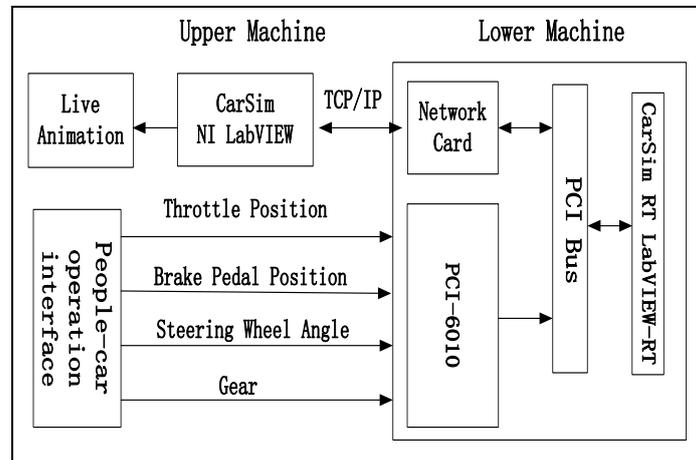


Fig-1: HIL simulation system structure



Fig-2: HIL physical configuration diagram

Real-time simulation model of vehicle

CarSim, a Professional vehicle dynamics modeling software, was used to develop real-time simulation model of the vehicle. CarSim had a vehicle parameterized model database, eliminate a series of complex process which the user established the programming mathematical model. A front wheel drive and front wheel steering model was established in Carsim, in which parameters were shown table 1 and

Figure 3 was the CarSim parameterized model for vehicle. The model was consisted of suspension system, power transmission system, braking system, steering system, tire and car body. The vehicle model not only can simulate the limit condition of the vehicle state with high accuracy, but also can be used for stability control simulation test and result analysis. In addition, the vehicle model could be real-time calculated and satisfied the requirement of HIL test bench [8].

Table-1: A front-wheel-drive and front wheel steering model parameters

Parameter	Value
Sprung mass /kg	1230
Center of mass to the front axle /m	1.04
Center of mass to the rear axle /m	1.56
Height of center of mass /m	0.54
Yaw inertia(Izz)/kg.m ²	1343.1
Front Wheel centers /m	1.48
Rear Wheel centers /m	1.485
Free radius/m	0.31



Fig-3: CarSim parameterized model for vehicle

The simulation program

CarSim, an independent operate vehicle dynamics simulation software, could be applied to different real-time system. Mechanical Simulation Company respectively developed different system interface module, included the graphical user interface (GUI) and the corresponding real-time system, real-time solver (DLL and LLB). In view of the LabVIEW RT, CarSim designed simulation initialization *_Init.vi, single step iterative *_Step vi, simulation end *_Terminate vi, 3 subroutine vi. * represent different topology structure of vehicle. Each sub-vi can call a function of the corresponding dynamic function library of topological vehicle structure by calling the function node in LabVIEW. Structure of HIL simulation program was shown in Figure 4. During the development of the main

application, two timing cycle was created, in which one was vehicle model simulate, the other was a physical signal data acquisition cycle. One timing source was used by two loops, through Shared variables for data exchange between them. The HIL simulation system was constructed under LabVIEW RT. In the simulation cycle, firstly, the CarSim model was be initialized, it was called the initialize vi. At this time all the information of CarSim GUI would be passed to the model solver. It included the vehicle assembly feature parameters, environmental parameters, pavement parameters, operation mode etc. At each simulation iteration, LabVIEW would call the vi of CarSim single-step iteration, each step could accept external signal and output signal of the simulation state, the end of the cycle was called the terminates vi release resources.

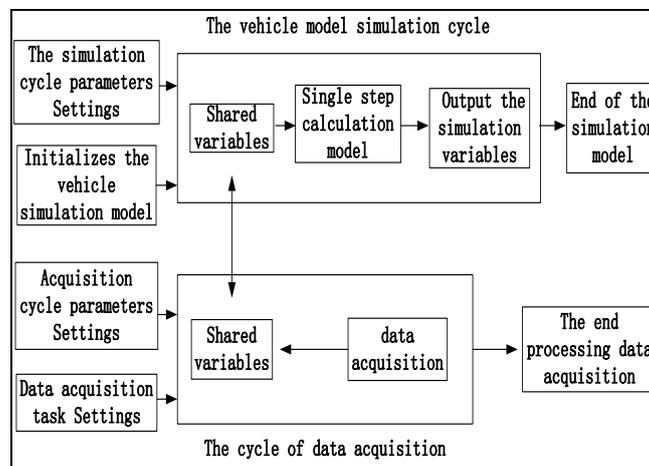


Fig-4: HIL simulation program structure

HIL SIMULATION TEST AND THE RESULTS

In this paper, after the construction of HIL simulation test platform was completed, Lemniscate track HIL simulation experiment was carried out to verify the effectiveness of the HIL simulation test platform. The test plan was developed based on the test process of steering portability experiment in national standards. In the upper machine, CarSim software was used to simulate the standard lemniscate track road. The driver model vehicle simulation experiment was carried out first, and then the driver practical HIL vehicle simulation test. At the beginning, the operator turn the steering wheel, drive the front wheel rotation and the front wheel Angle signal would be input to the real-time vehicle model of lower machine. After the calculated results were output to the vehicle model, the ideal lemniscate trajectory data would be tracked, so as to complete the HIL simulation test.

Simulation test set-up

In the simulation test, the vehicle model parameters were shown in Table 1, parameters of a front-wheel-drive and front wheel steering model. The polar equation of Lemniscate track:

$$l = d\sqrt{\cos 2\varphi} \tag{1-1}$$

The curve radius R of arbitrary point on the trajectory determined by the following equation:

$$R = \frac{d}{3\sqrt{\cos 2\varphi}} \tag{1-2}$$

When $\varphi = 0^0$, the curvature radius of Lemniscate vertex was the minimum value:

$$R_{min} = \frac{d}{3} \tag{1-3}$$

R_0 , the minimum turning radius of the outer wheel center trajectory of the front wheel:

$$R_0 = \frac{L}{\sin \theta_{max}} + \frac{b - M}{2} \tag{1-4}$$

In which, L was the distance between the automobile front axle and rear axle, θ_{max} was the lateral wheel maximum Angle of car steering wheel, b was the front wheel track, M was the center distance of King pin, R_{min} , the minimum radius of curvature lemniscate, was the 1.1 times of front lateral wheel minimum turning radius: namely

$$R_{min} = 1.1R_0 \tag{1-5}$$

Two pegs were placed on each side of the path at the Vertex and midpoint of lemniscate, a total of 16 pegs. The distance between the Peg and the centerline of the path was the half of the width of the vehicle and

another 50 cm, or the half of the width of channel of turning round and another 50 cm [9-10]. Therefore, lemniscate track was drawn in the Figure 3 and the simulation animation was in the Figure 4. In the process of simulation test, vehicle always kept $10\text{km}\cdot\text{h}^{-1}$ of longitudinal speed. In the driver model simulation test of vehicle, the driver model was set to follow the driver's path. In the pilot operation HIL simulation tests of the vehicle, the operator turned the steering wheel to complete the lemniscate test. In order to ensure the reliability of contrasted results between the pilot model vehicle simulation test and the pilot practice HIL vehicle simulation test. In this paper, the 10 m distance was increased in the start and terminate of lemniscate. The simulation time of driver's actual operation HIL vehicle simulation test and the pilot model vehicle simulation test were set to 28 s according to the pilot model vehicle simulation test results.

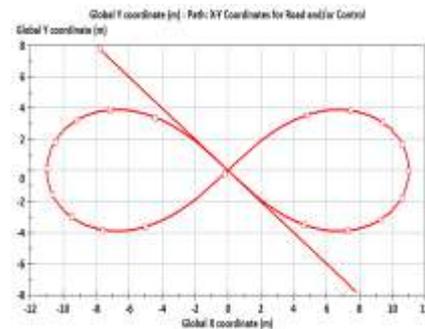


Fig-5: Lemniscate track

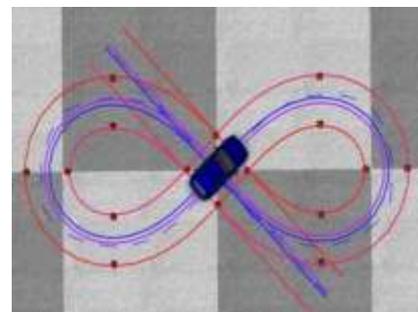


Fig-6: Lemniscate simulation animations

Simulation test

The vehicle model was established by CarSim and the data acquisition program was written by LabVIEW in the upper machine were deployed to the lower machine. And then the Steering portability simulation test was conducted. Firstly, the ideally yaw rate (body-fixed) curve would be painted according to the driver model vehicle simulation test. Secondly, the pilot operate vehicle HIL simulation test would be started, The operator turned the steering wheel, the front wheel Angle signal was imported to the vehicle motion model, After the vehicle model was calculated, the steering wheel Angle, yawing rate (body-fixed) and the vehicle's movement track curves was output by the vehicle model, and it realized the track for ideal curve.

Finally, the experimental data was saved. The related curves Figure-5, Figure-10 were involved in the process of test.

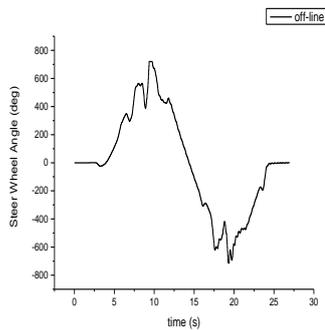


Fig-7: Simulation test results of vehicle steering wheel angle

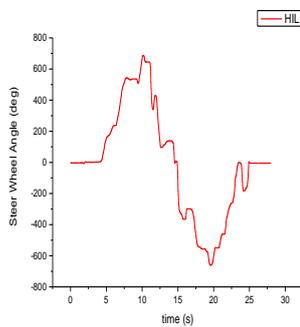


Fig-10: HIL simulation test results of vehicle steering wheel angle

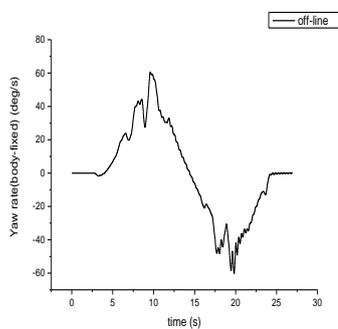


Fig-8: Simulation test results of vehicle yaw rate (body-fixe)

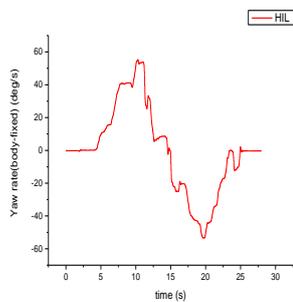


Fig-11: HIL simulation test results of vehicle yaw rate (body-fixe)

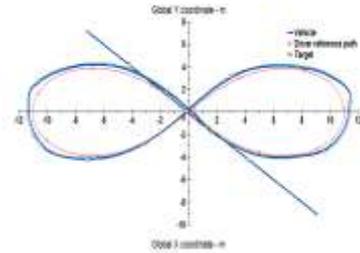


Fig-9: Simulation test results of vehicle trajectory

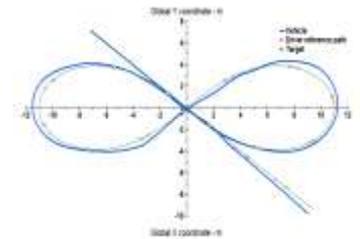


Fig-12: HIL simulation test results of vehicle trajectory

Figure 7 ~ 9 were the lemniscate simulation test results of the driver model for path following. Figure 10-12 were the HIL simulation test results of the drivers' actual operation. In the same conditions of simulation road and simulation time, the trend of the steering wheel Angle, yaw rate (body-fixed) and the trajectory of vehicle were the same in the driver model simulation test and driver operation HIL simulation test.

The analysis of simulation test results

On the HIL simulation platform, the pilot practical HIL vehicle simulation test could be conducted. Due to the purpose of this article was to verify the real-time reliability of the test bench, so reference the steering portability test in national standard, the lemniscate test of input steering wheel angle was carried out. The simulation results show that, the whole system hardware and software operating normally, the physical signal data acquisition, the internal data transmission of target machine can complete real-time, and it could reflect the operator's intentions in real time. LabVIEW RT provided a real-time execution trace tool, it could detect the real-time of program and check the execution time of each thread and sub-program in the program. Results showed that the average time of each model iteration was less than 500us, the average time of signal measuring was less than 1ms, each cycle time was specified as 1ms, so the HIL simulation platform was completely meet the requirements of real-time operation.

CONCLUSION

This paper used the widely used LabVIEWRT and CarSimRT in the industry to set up the vehicle HIL simulation test system. Complete the connection of physical hardware and software environment, and set data acquisition, model calculation, data interactive real-time operation mechanism. This system used the

industrial computer IPC-610-L of Advantech as the real-time target machine. It was almost equal to NI PXI on the running speed, at the same time it also had the high stability and greatly saved the development costs of HIL simulation test platform. The HIL simulation test platform could be convenient for the HIL simulation test of pilot practical operation and had a very good extensibility and real-time performance. It built a good foundation of hardware and software for the more complex ESC controller HIL study.

REFERENCE

1. Hanselmann H; advances in Desktop Hardware-in-Loop Simulation. SAE Paper 970932, 1997.
2. Gehring J, Schutte H; a hardware -in -the -Loop Test Bench for the Validation of Complex ECU Networks. SAE Paper 2002-01-0801, 2002.
3. Ding H, Guo K, Zhang J; Development and Application of the Hardware and Driver-in-the-loop Test Rig for Automotive Electronic Stability Programs. Automotive Engineering, 2006; (4): 346-350.
4. Robet H; Bishop National Instruments. Lab VIEW 2009 Student Edition [M]. BeiJing: Publishing House of Electronics Industry, 2014.
5. Xie QI, Fang YU. Research on Key Techniques of Developing Test System Based on LabVIEW[J].Machine Tool & Hydraulics, 2005; (10): 54-57.
6. Gao M, Zhao N, Zhang R; Development and Simulation Research of the ESP Hardware in the Loop Simulation Test Bench Based on Lab VIEW. Research on Development, 2013; (6):053-061.
7. Wu HD, Guo K, Lu D; The Simulation of Hardware-in-the-Loop based on LabVIEW RT. Automobile Technology, 2010; 9: 1-3.
8. Guo K, Fu H, Ding H, Lu D, Jin L; Development of Controller for Vehicle Stability System Based on CarSimRT[J]. Automobile Technology, 2008; 3: 1-4.
9. Yu F, Zhao L, Wang J, Zhao B, Gao M; Study on Simulation of Steering Portability Based on Lab VIEW. Journal of Hubei University of Automotive Technology, 2013; 27(2): 23-26.
10. GB/T 6323.5-94, Controllability and stability test procedure for automobiles--Steering efforts test procedure.