A Hardware-in-loop Simulation Test-platform For the Intelligent Vehicle's Steering Control System

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***Abstract*—During the research of intelligent vehicle steering control algorithm, it is extremely dangerous for the intelligent vehicle to do solid trial under high-speed circumstance. According to the Visual C++ and Matlab, a hardware-in-loop simulation test-platform (HILSTP) for the intelligent vehicle's steering system has been set up. The test-platform which is designed on the basis of the steering system of the vehicle can manipulate directly the steering mechanism, so it is able to simulate accurately the steering control of the intelligence vehicle under high-speed circumstance. HILSTP can expediently analyze the steering control algorithm, decrease the trial expenses and trial risk, and improve the development efficiency.**

***Keywords*—Intelligent Vehicle ; Steering Control System ; HILSTP ; Lateral Dynamics Model**

I. Introduction

The reliability of control system for the intelligent vehicle affects directly the vehicle safety performance and ride comfort quality. During the research for steering control algorithm of the intelligent vehicle, we find that the traditional development methods need a long period and spend plenty of trial expenditure, especially, the solid trial is extremely dangerous for the intelligent vehicle under high-speed circumstances. So it is necessary to design a hardware-in-loop simulation test-platform (HILSTP) for the steering algorithm research.

II. Hardware Design

A typical HIL simulation system should include real-time sensors, controller, man-machine interface and Simulation-analysis platform. In this paper, the HILSTP of the steering control system mainly includes an angular sensor, a DC-motor, a DSP regulator and a computer. The hardware structure and logic relation is shown as Fig.1. The angular sensor can collect the real-time angle of the steering wheel. As a driving device, the DC- motor makes the steering wheel turn left or right above 3 rounds respectively. When the DSP regulator receives an instruction from the computer, it can make the DC-motor turn quickly and can transmit data which includes the angle and the angular velocity to the computer.

Some main components of the HILSTP are shown as Fig.2 and Fig.3.

Since the hardware structure of the HILSTP is same to the structure of the intelligent vehicle's steering system, HILSTP

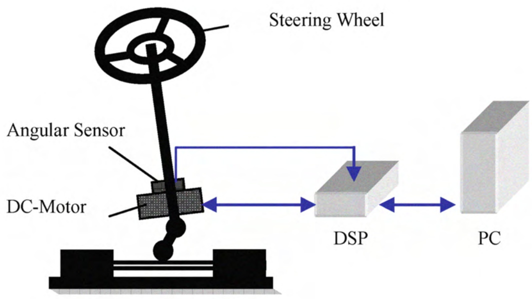

Fig.1. HILSTP's hardware structure

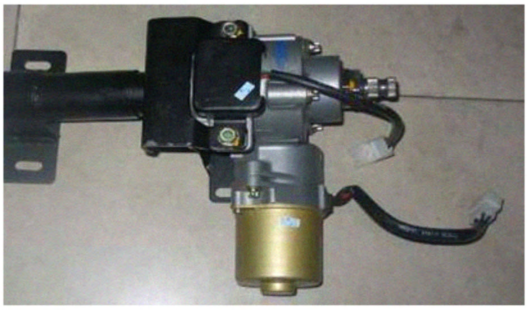

Fig.2. DC Motor

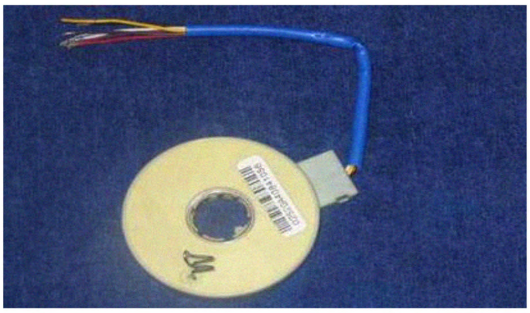

Fig.3. Angular Sensor

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can imitate perfectly the lateral navigation of the intelligent vehicle.

III. SOFTWARE DESIGN[3][8]

HILSTP's Software design is completed by means of Visual C++ and Matlab/Simulink tool. The software structure embodies road recognition，obstacle detection, vehicle lateral dynamics model and steering algorithm HIL. The flow char of software is shown as Fig.4.

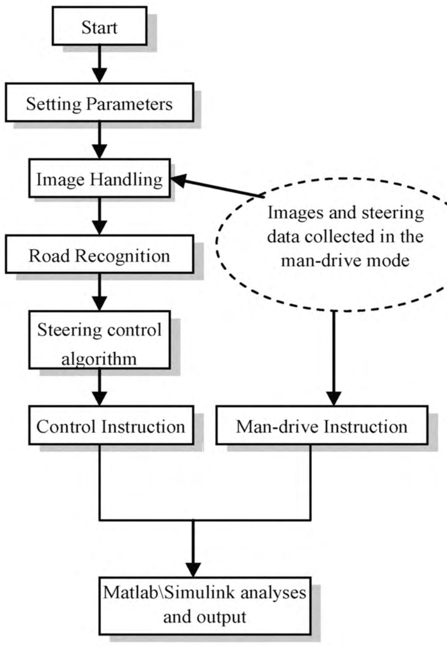

Fig.4. HILSTP's flow chart

The work process of HILSTP system is detailed describe as follows: when starting the system some important parameters are set beforehand, for example, the maximum velocity of the intelligent vehicle, the width of the road and so on. Secondly, the road and obstacles are detected from the collected images. Thus, we easily get the road edge range lines and the intelligent vehicle location. From the information of the road and the vehicle, the vehicle yaw angle can be computed. If the yaw angle is deviated excessively from the angle which is collected in the man-drive mode, we can adjust repeatedly some parameters of the steering control algorithm. Ultimately, the algorithm is reliable and appropriate for intelligent vehicle to do solid trial under high-speed circumstance.

The software main interface is shown as Fig.5.

IV. SIMULATION AND EXPERIMENT

A. Vehicle Lateral Dynamics Model[9]

In order to analyze the performance of the steering control algorithm, we must set up an accurate vehicle lateral dynamics model. So a two- tires dynamics mode shown as Fig.6 is proposed in the paper.

Supposed the tire's lateral force is linear to tire's lateral angle, the lateral force can be described as (1) and (2).

$$F_f = C_f \beta_f. \qquad (1)$$

$$F_r = C_r \beta_r. \qquad (2)$$

Figure 5. Software interface of HILSTP

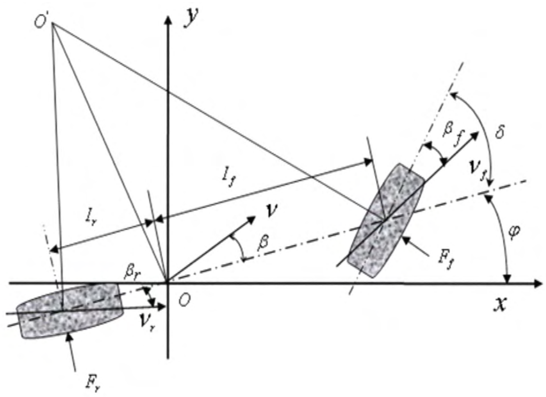

Figure 6. Two-tires dynamics mode

According to the rigid motion theorems the distance from the motion center point O' to the gravity centre point O is the swerve radius of a vehicle. The velocity of mass center point is expressed in the can be expressed in (3).

$$V = \dot{\phi} R. \qquad (3)$$

Based on the relation of the vector space In the Fig.6，(4) can be easily get as follow:

$$\phi + \beta \quad \dot{y} = V \sin(\phi + \beta). \qquad (4)$$

Considering the values of ϕ and β are both small, we can regard that the lateral force is vertical to the x axis. Thus the equations of the vehicle lateral dynamics mode can be described as (5) and (6).

$$m\ddot{y} = F_f + F_r. \quad (5)$$

$$I\ddot{\phi} = l_f F_f + l_r F_r. \quad (6)$$

The geometrical relations of (7) and (8) also easily concluded.

$$\delta - \beta_f = \beta + l_f / R. \quad (7)$$

$$\beta_r = l_r / R - \beta. \quad (8)$$

So the differential equations of vehicle lateral motion mode can ultimately be remarked as (9) and (10).

$$m\ddot{y}=(l_rC_r-l_fC_f)V/\dot{\phi}+(C_f+C_r)\phi-(C_f+C_r)\dot{y}/V+C_f\delta. \quad (9)$$

$$I\ddot{\phi}=-(l_f^2C_f+l_r^2C_r)\dot{\phi}/V+(l_fC_f-l_rC_r)\phi-(l_fC_f-l_rC_r)\dot{y}/V+l_fC_f\delta. \quad (10)$$

On the basis of the differential equations and the Matlab/Simulink tool, the HILSTP's steering motion simulation mode is set up. The detailed frame of simulation mode is described in the Fig.7.

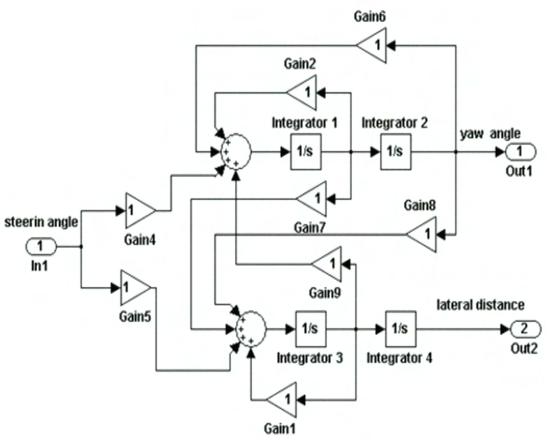

Figure 7. Simulation mode of the HILSTP's steering motion

B. *Steering Control Algorithm*

The Steering control algorithm called Human-Simulating Control Model is quoted in the paper. The input parameters include orient error angle, lateral distance error and velocity of the vehicle. The output parameters include steering angle of the steering wheel, angular speed of the DC-motor. The algorithm can be described as (11), (12) and (13).

$$y(\alpha, le, v) = y(\alpha, le) f_{v-\alpha}(v). \quad (11)$$

$$v(\alpha) = v_0 f_{\alpha-v}(\alpha). \quad (12)$$

$$w(v) = w_0 f_{v-w}(v). \quad (13)$$

(11) is the output of steering angle with lateral error (*le*) and orient error (α) as the input and considering the influence of the vehicle speed. (12) is the output of vehicle speed which is linear to the orient error. And (13) is the output of the angular speed of the DC-motor.

C. *Experiment*

In the paper, the experiment includes pure algorithm simulation, HILSTP test and solid vehicle auto-drive test. In the pure algorithm simulation we analyze just the algorithm of the intelligent vehicle's steering control mode, and the hardware system has not been taken into account. But in the HILSTP test, the algorithm is integrated with the real-time hardware system that includes the steering mechanisms and some sensors. It is proved in the paper the steering control algorithm is improved greatly by means of the HILSTP test. The solid vehicle auto-drive test mainly monitors the control performance of the steering control algorithm.

The result of the pure algorithm simulation and the HILSRT test are respectively shown as Fig.8 and Fig.9. It is evident that the HILSTP can improve the steering control algorithm's reliability and simulate better the real drive-environment.

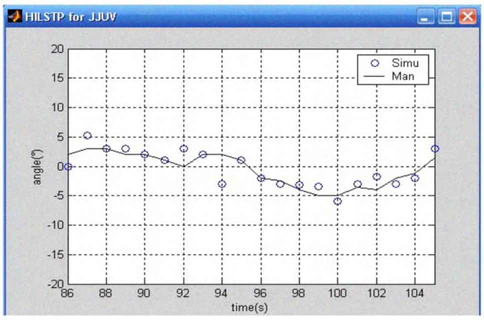

Figure 8. The result of the pure algorithm

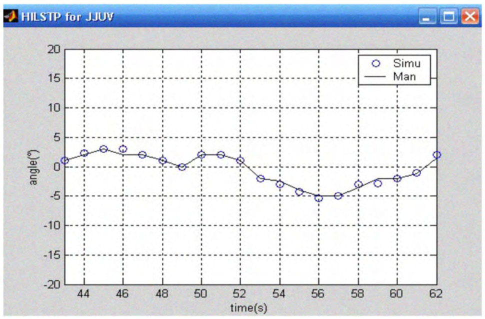

Figure 9. The result of the HILSTP test

V. CONCLUSION

In this paper, we design a HILSTP for the intelligent vehicle. The HILSTP provides a better tool to research and analyze the steering control algorithm. Most of important, the trial expenses and trial risk greatly decrease. The experiment shows a better performance of the HILSTP.

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