

Development of ABS ECU with Hardware-in-the-Loop Simulation Based on Labcar System

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ABSTRACT

This paper presents how hardware-in-the-loop (HIL) simulations have been used for testing during the development of ABS (Anti-lock Braking System). The Labcar system of ETAS is a popular tool for HIL tests. The vehicle model which is built in Matlab/Simulink is downloaded to run in RTPC (Real-time PC). The Labcar software, Integration Platform (IP), can configure boards which is a link between the model and ABS ECU. In this paper, a classical logic threshold control algorithm is adopted in ABS ECU. Through Labcar Experiment Environment (EE) various parameters can be monitored and modified conveniently.

The HIL test of ABS ECU is implemented on high or low - adhesion road respectively. The results show that, although response lag exists in the hydraulic braking system, the curves of velocity and pressure in wheel cylinders can be close to those on real road with proper adjustment of control parameters. So HIL simulations are invaluable, when considering the short development time required in the automotive industry.

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INTRODUCTION

"V mode", widely applied in the development of modern automotive ECU, mainly consists of five steps: off-line functional design, RCP(Rapid Controller Prototyping), target code generation, HIL, calibration and matching, of which HIL is an important step to test the core functions of ECU. Currently mainstream HIL simulation systems include dspace, ETAS Labcar, MatlabxPC and Labview RT, etc[1,2,3].

After comparison, ETAS Labcar system on the basis of the distributed framework of Ethernet can meet the different needs through the flexible configuration of boards. Since Labcar wheel speed board ES1337 can simulate various types of wheel speed signals, it's especially suitable for HIL of ABS/ESP.

As a mature electronic control product, ABS has been widely used in all kinds of vehicles. At present, ABS ECU normally adopts the logic threshold control algorithm, and it decides whether to increase, decrease, or hold the pressure according to the thresholds of wheel deceleration and slip rates so that the slip rate fluctuates near the optimal value. Therefore, the performance of ABS ECU is closely related to factors like vehicle dynamics model, tire model and road environment and the braking system, etc. Compared with the real road test, applying the real ABS ECU and hydraulic brake system with

the combination of virtual drivers, road environment and HIL platform established by vehicle models can not only reduce the development costs and lessen the time but also simulate various dangerous working conditions.

This paper is mainly concerned about the HIL test on ABS ECU based on logic threshold algorithm. It firstly presents the control algorithm, establishes the HIL testing system, then introduces the hardware and software platforms of Labcar. On the basis of VDYM human-car-road model, it completes the simulation models needed for HIL tests afterwards. Finally the hydraulic brake test bench testifies the performances of ABS ECU on high-adhesion and low-adhesion roads. Through HIL tests, control algorithm and the model parameters can be easily modified in time so as to achieve the best control effects.

CONTROL METHOD

Control method is the core part of ABS, including logic threshold control, PID control, SMC control, fuzzy control, neural network control and other intelligent control.

As the main method of current products, logic threshold control method has many advantages. For instance, this method doesn't involve concrete mathematical model and is relatively simple for nonlinear system control application. Figure 1 shows the ABS control logic.

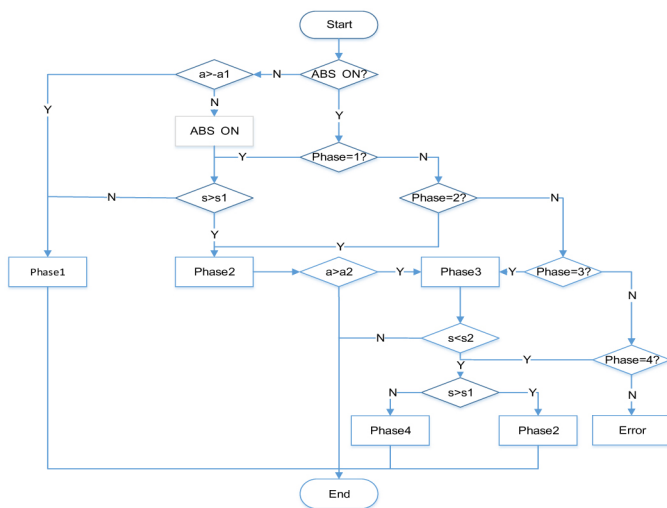


Figure 1. ABS control logic

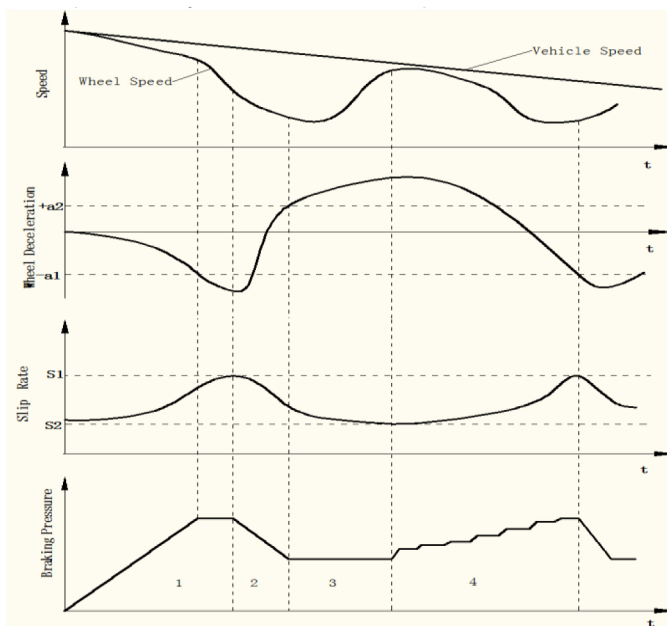


Figure 2. Four-phase control logic process diagram

Four-phase control logic process diagram sees in [Figure 2](#) below. In the figure, 1~4 represent four phases; a_1 and a_2 are wheel deceleration threshold values, s_1 and s_2 are wheel slip rate threshold values. The idea of four-phase control logic raised in this paper is as follows: When vehicle emergency braking happens, once the wheel deceleration is less than the first threshold of wheel deceleration a_1 , wheels will be controlled by holding the pressure. But because of the influence of the mechanical-hydraulic system lags, wheel slip rate will continue to increase for a period of time till the wheel slip rate is more than s_1 . This process above is called the first phase. The second phase is that after the wheel slip rate is more than s_1 , wheels will be controlled by decreasing the pressure. With the decrease of the brake pressure, wheel deceleration will increase. When it rebounds to a_2 , the third phase begins in which wheels will be controlled by holding the pressure. By the time, because wheel deceleration is in the

increasing stage, the wheel speed will be bound to rise again and the slip rate will also decrease. When the slip rate is less than s_2 , the pressure will be increased step by step into the fourth phase. A cycle ends when the slip rate reaches s_1 .

a_1 decides the time when ABS starts to decrease or hold the pressure. Its value has a great effect on the largest slip rate and whether the wheels are locked, so it's the most important threshold value of all. a_1 has to be greater than the wheel deceleration when inertia wheel reaches the peak-adhesion coefficient on high-adhesion road and less than the wheel deceleration when inertia wheel reaches peak-adhesion coefficient on low adhesion road. If a_1 is too large, the wheel brake pressure will be too high and slip rate will be so big that the tire wears out. It's also likely to reduce the road adhesion coefficient and the wheel is easy to be locked. When a_1 is too small, the system will decrease the pressure or hold the pressure too early. It leads to the low wheel braking pressure and small slip rate, and affects the actual utilization of the tire-road friction coefficient. In general, high-adhesion road should have larger threshold value a_1 and low-adhesion road should have smaller threshold value a_1 .

a_2 decides when to hold the pressure. When a_2 is too large, the pressure will decrease a great deal after the system decrease it, which causes the wheel slip rate to become too low and thus influences the utilization of adhesion coefficient. What's worse, it may even result in a lack of braking force. As a consequence, wheel speeds become larger than vehicle speed because of the inertia on high-adhesion road. If a_2 is too small, it will leads to the insufficient recovery of wheel speeds and a large slip rate during braking.

s_1 and s_2 are mainly based on the results of the optimal slip rate identified on current road. And s_1 plays a role at the beginning of the control loop while s_2 controls the slip rate in a reasonable range[4,5].

Threshold matching is the most important step which costs the longest time. Different road always needs different threshold values. With complex and changeable road conditions, it's hard to realize threshold matching and control. Using the idea of self-adaption for reference, main threshold values are designed to implement more accurate self-adaption on the basis of thorough analysis how every threshold value influences control of ABS.

This paper completes ABS bench tests on both high-adhesion road (0.8) and low-adhesion road (0.2) successfully. With adjustment for many times, optimized threshold values are suitable for these two kinds of roads. In general, the road adhesion coefficient ranges from 0.2 to 0.8. These two sets of threshold values can be regarded as critical threshold values. Then, according to the result of road adhesion coefficient identified, each threshold value will be confirmed by linear interpolation between two sets of critical threshold values.

ARCHITECTURE FOR HIL TEST

As shown in Figure 3, the hardware and software of ABS HIL simulation system includes Labcar PC, RTPC, boards, ABS ECU and Hydraulic Brake System. ABS ECU is developed based on the 16-bit low power microcontroller, of which the frequency capture ports are used to collect four magnetoelectric wheel speed signals and one external interrupt port is used to receive the brake switch signal which switches ABS. In addition, twelve PWM output ports are used to switch twelve electromagnetic valves and the other one drives the plunger pump. After applying brake, the hydraulic brake system transmits four wheel cylinder pressure signals to RTPC.

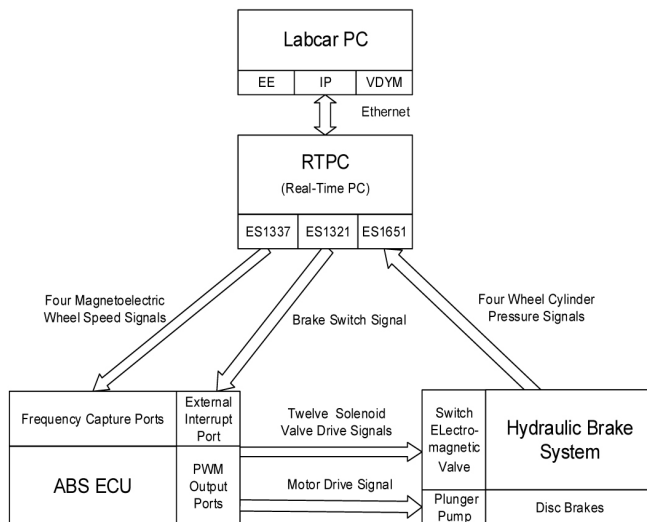


Figure 3. ABS HIL simulation system

Labcar Hardware Platform

Labcar hardware platform consists of RTPC and boards. RTPC is mainly responsible for the real-time calculation of simulation model and it is connected with Labcar PC and boards through Ethernet. The needed boards in this experiment are ES1130, ES1391, ES1321, ES1651 and ES1337. ES1130 is used for data communications between RTPC and each board. Power board ES1391 supplies power for the system with the output voltage 5V and current within 0.5A. Digital signal processing board ES1321 produces the simultaneous signals of simulation model and ABS ECU. That's to say, when the virtual environment in RTPC fulfills the initial working conditions of ABS, the simultaneous signal triggers the operation of ABS ECU. Analog signal conditioning board ES1651 measures the four-way wheel cylinder pressure. Wheel speed sensor simulation board ES1337 can simulate five different kinds of wheel speed signals. In this experiment, it simulates the sinusoidal signals similar to magnetoelectric wheel speed sensors.

Labcar Software Platform

Labcar software platform consists of system configuration software IP (Integration Platform) and user interface software EE (Experiment Environment). IP has five functions as follows.

1. The configuration of boards.
2. The compiling and debugging of simulation model.
3. The signal connection between boards and model.
4. The definition of messages of CAN communication.
5. The unit conversion between the input/output values of the model and the physical signals of boards.

The operation of IP is showed in Figure 4.

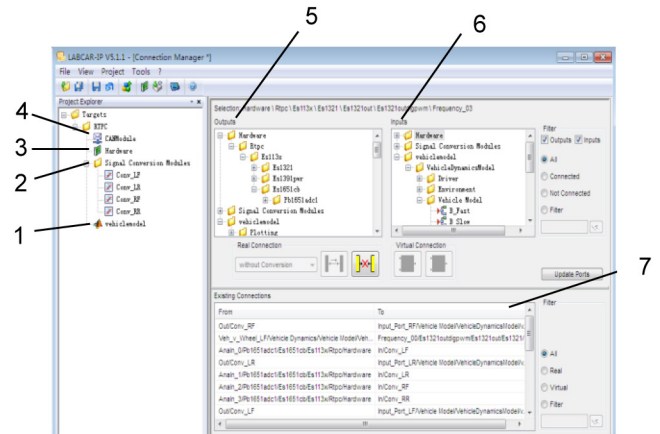


Figure 4. IP software interface

- 1.VDYM Model 2.Signal Conversion Module 3.Hardware 4. CAN Module 5.Outputs 6.Inputs 7.Existing Connections

The CAN module is a communication controller implementing the CAN 2.0B protocol as defined in the BOSCH specification. CAN messages which adopt standard data frames are all 8-byte long and the bit rate is programmed to 500 kbps. The CAN module transmits four values of wheel speeds to ABS ECU. Each message frame includes 8 bytes data and each value occupies two bytes.



Figure 5. EE software interface

- 1.RT-Plugins 2.Signal Generator 3.Datalogger 4.Instrumentation 5. Driver Layer 6.Wheel Speed and Vehicle Speed Layer 7.Wheel Cylinder Pressure Layer 8.Slip Rate Layer 9.Control Layer