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Hardware-in-the-loop Simulation of Traction Control Algorithm Based on Fuzzy PID

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Abstract

In this paper, a traction control algorithm based on fuzzy PID is proposed, and a hardware Hardware-in-the-loop (HIL) test bench which is based on the xPC Target™ product of MATLAB® is introduced. The control algorithm is validated using the test bench and the test results of show that the algorithm can control the spin of driven wheels effectively.

Keywords:Traction control; Hardware-in-the-loop; fuzzy PID;

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1. Introduction (Heading 1)

It is a known fact that development of automotive control systems using hardware-in-the-loop (HIL) is a very mature methodology. There are several suppliers with available tools like dSPACE, ETAS and IPG, and a great number of successful applications. Besides reduced dependence on physical test systems, HIL systems have other virtues: perfectly repeatable tests and perfect control of test environment variables. Over the last two decades many automotive and commercial vehicle makers have added virtual testing or hardware-in-the-loop (HIL) testing of electronic control system to their repository of tools.

TCS (Traction control system) can guarantee stability and optimum traction during acceleration, particularly on asymmetrical road surfaces and during cornering maneuvers by controlling the slip ratio of driven wheels to the target slip ratio, which is typically the ratio at which the road adhesion coefficient is at its maximum. Typically engine torque control and driven wheel braking control are used. In recent years, the study of TCS focuses on the application of modern control theory to TCS, TCS for electronic vehicles and hybrid vehicles.

In this paper, a traction control algorithm based on fuzzy PID is proposed, and a hardware Hardware-in-the-loop (HIL) test bench used to validate the algorithm is introduced. The test bench which is based on the xPC Target™ product of MATLAB® is low cost and high efficiency. After the description of the

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hardware and software of test bench and the control algorithm in detail, the test results are listed in the last part of the paper.

2. Structure of hardware-in-the-loop simulation system

The hardware in the loop test bench consists of two parts .i.e. the hardware part and the software part.

A. Structure of the test bench

The hardware part of the test bench is based on the xPC Target™ product of MATLAB®, it consists of a desktop computer as host PC, an industrial control computer as target PC, a drive circuit to drive the motor and solenoid valves in the Hydraulic Control Unit (HCU) and the stepping motor in the electronic throttle, an electronic throttle, 4 pressure sensors, a HCU and a suit of vehicle hydraulic braking system.

Fig. 1. HIL test bench of traction control system

During simulation, the vehicle model and control algorithms built in MATLAB®, Simulink®, and Stateflow® software are converted to executable code using the host PC with Real-Time Workshop®, Real-Time Workshop® Embedded Coder™, Stateflow® Coder™ software, and a C compiler. The host PC and target PC are communicating through TCP/IP protocol. There are two boards in the industrial control computer for the purpose of data acquisition and PWM generation, which are PCL 812PG and PCI 6602 produced by ADVANTECH and National Instruments respectively. The PCL 812PG is used to acquisition the analog signals from the pressure sensors. The PCI 6602 is used to generated PWM signals to control the motor and the solenoid valves in the HCU and the stepping motor in the electronic throttle, as it can not provided enough power, dedicated drive circuit is introduced. To control the braking pressure of four brake cylinders and to build braking pressure actively, a HCU of BOSCH ESP 8.0 is used. The four pressure sensors which are used to record the brake pressure are mounted near each brake cylinder between each brake and the HCU.

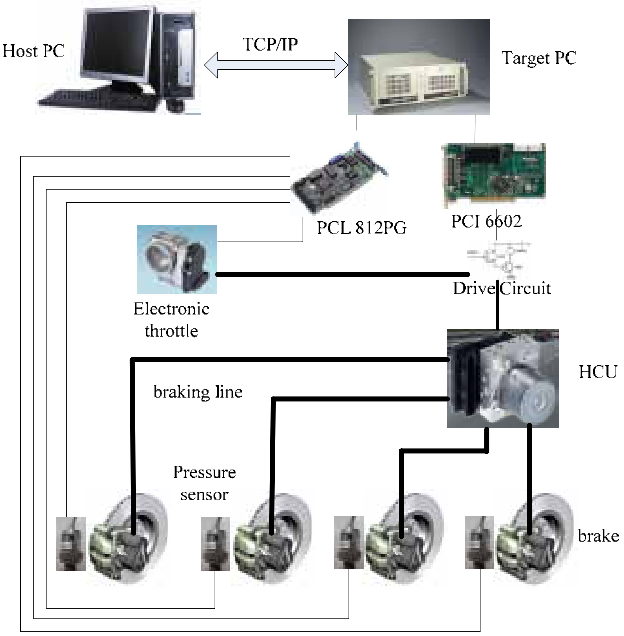

Fig. 2. Schematic diagram of HIL test bench

B. *Vehicle dynamic modeling*

To validate the traction control algorithm been developed, vehicle model is constructed under the environment of MATLAB®/Simulink®. The vehicle coordinate system is a vehicle-fixed right-hand orthogonal axis system. The system includes a seven-degree-of-freedom dynamics model describing the motion of vehicle and wheels. A brief summary of this vehicle model and engine and tire models are presented hereinafter.

1) *Engine model*

The character of engine can be described by the steady state character and the transient state character. The steady state of engine can be modeled by lookup table and the transient state can be modeled by a first order system with time lag, as equation 1 shows:

$$M_e = M_s \frac{1}{1+T_1 s} e^{-T_2 s} \tag{1}$$

Where: Ms is the steady state torque of engine, Me is the transient torque of engine, T1 and T2 are time constant.

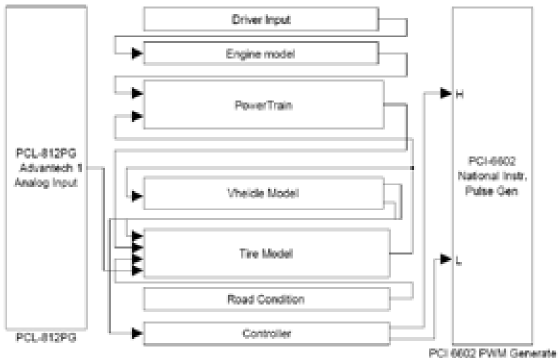

Fig. 3. Structure of simulation model of HIL test bench

2) Vehicle model

$$M\cdot\left(\dot{V}_x-\dot{\psi}\cdot V_y\right)=\sum F_x \tag{2}$$

$$M\cdot\left(\dot{V}_y+\dot{\psi}\cdot V_x\right)=\sum F_y \tag{3}$$

$$I_z\cdot\ddot{\psi}=\sum M_z \tag{4}$$

$$I_i\cdot\dot{\omega}_i=F_{x_i}*r_{d_i}-T_{b_i}-T_{f_i} \tag{5}$$

$$\sum F_x=\sum_{i=1}^{4}\left(F_{x_i}\cdot\cos\delta_i-F_{y_i}\cdot\sin\delta_i\right) \tag{6}$$

$$\sum F_y=\sum_{i=1}^{4}\left(F_{x_i}\cdot\sin\delta_i+F_{y_i}\cdot\cos\delta_i\right) \tag{7}$$

Where:

M is the mass of vehicle, $\dot{V}_x$ is the longitudinal acceleration of vehicle, $\dot{V}_y$ is the lateral acceleration of vehicle, ψ is the yaw rate of vehicle, Iz is the rotational inertia of vehicle about z axle of vehicle in vehicle reference system, Fxi and Fyi are tire forces in the x direction and y direction in wheel systems.

3) Tire model

$$F_x=\begin{cases}C_sS_sl_n^2+\mu_xF_z(1-3l_n^2+2l_n^3) & S_s<S_{sc}\\ \mu_xF_z & S_s\ge S_{sc}\end{cases} \tag{8}$$

$$F_y=\begin{cases}C_aS_al_n^2+\mu_yF_z(1-3l_n^2+2l_n^3) & S_a<S_{ac}\\ \mu_yF_z & S_a\ge S_{ac}\end{cases} \tag{9}$$

$$M_z = \begin{cases} \left[C_a S_a \left(-\frac{1}{2} + \frac{2}{3} l_n \right) + \frac{3}{2} \mu_y F_z \right] \cdot l_n^2 \cdot l & S_a < S_c \\ 0 & S_a \geq S_c \end{cases} \qquad (10)$$

Where:

$$S_n = \frac{1}{3\mu F_z} \sqrt{(C_s S_s)^2 + (C_a S_a)^2}$$

$$l_n = 1 - S_n$$

$$S_{Sc} = 3 \frac{\mu F_z}{C_s}$$

$$\mu = \sqrt{\mu_x^2 + \mu_y^2}$$

$$S_{ac} = \frac{C_s}{C_a} \sqrt{S_{sc}^2 - S_s^2}$$

3. Fuzzy pid controller for traction control

Traction control system mainly controls the output torque of engine and braking torque of driven wheels to prevent the driven wheels from spinning. The target of the system is to control the slip ratio of driven wheels to the region where the coefficient of friction between tire and road is at its optimum. This can improve the acceleration performance and the lateral stability of vehicle driving on slippery road.

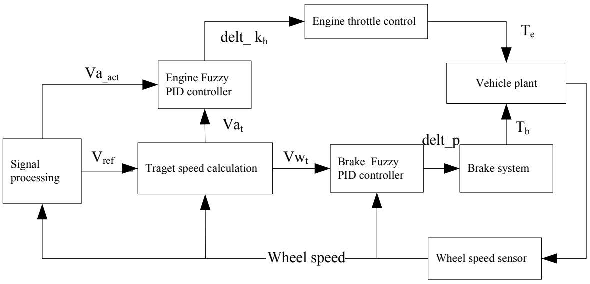

Fig.4. Structure of traction slip controller

The structure of the fuzzy PID traction control algorithm validated in the HIL simulation is shown in figure (4). As the slip ratio at which the coefficient of friction between tire and road is at its optimum varies with adhesion coefficient of the road and the vehicle speed etc. The first thing in TCS control is to calculation the target speeds. The target speeds including target speeds of driven wheels and target speed of drive shaft. The target wheel speeds can be calculated by vehicle reference speed and the target slip ratio, the target speed of drive shaft can be calculated by the average of the target speeds of driven wheels. As mentioned hereinabove, the target slip ratio varies with the road adhesion coefficient, so it is of advantage to determine the target slip ratio as a function of the two factors.

As following equations show:

$$V_{whl\_tar} = V_{ref} \cdot (1 + \lambda_{tar}) \qquad (11)$$

$$\lambda_{tar} = f\left(V_{ref}, \mu\right) \tag{12}$$

$$\mathrm{V}_{\mathrm{ds\_tar}} = \left(V_{whl\_tar\_L} + V_{whl\_tar\_R}\right)/2 \tag{13}$$

Where: V_{whl_tar} is the target speed of driven wheel; V_{ref} is vehicle reference speed; λ_{tar} is target slip ratio of driven wheel; V_{ds_tar} is the target speed of drive shaft; $V_{whl\_tar\_L}$ and $V_{whl\_tar\_R}$ are target speed of driven wheels on the left and right side of vehicle.

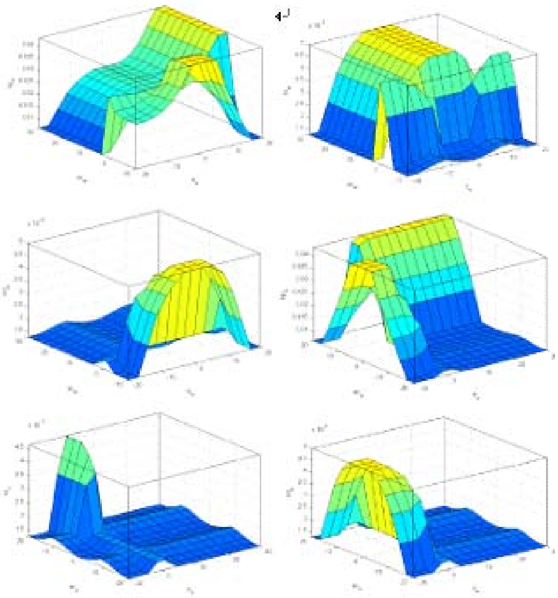

Fig.5. Structure of adaptive fuzzy PID controller

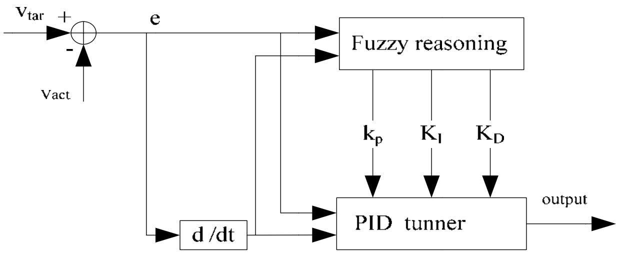

Fig. 6 Surface view of the parameters of fuzzy PID controller

After the target speeds been calculated, a fuzzy PID controller is used to control the engine throttle and the braking pressure of driven wheels. The difference between target drive shaft speed and actual drive shaft speed is input to the fuzzy PID engine throttle controller, where the actual drive shaft speed is the average of actual driven wheel speeds. The difference between target wheel speed and actual wheel speed of each driven wheel is send to the fuzzy PID braking controller. As shown in figure (4). The structure of fuzzy PID controller is shown in figure 5; the error and its derivation are sent to fuzzy reasoning block, from which the parameters of PID controller are decided. The surface views of the parameter K_P, K_I, K_D and e, Δe are shown in figure 8.

4. Simulation results of fuzzy pid traction control algorithm on test bench

Figure (7~9) show the simulation results of fuzzy PID traction control algorithm on the test bench. The simulation is about the maneuver of straight line acceleration for stop on low μ road. As both driven wheels show the tendencies of spinning, braking control of driven wheels and engine throttle control are activated.

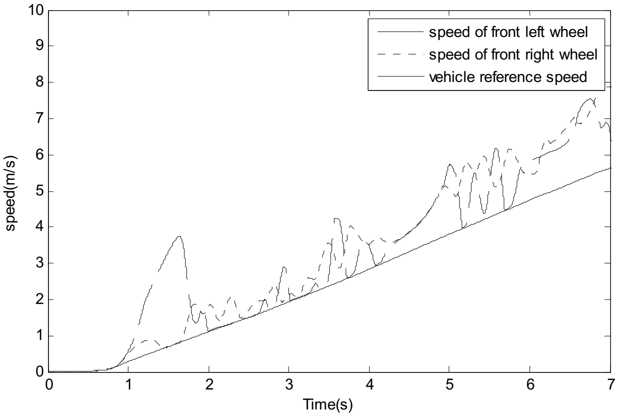

Fig. 7. Wheel speed and vehicle reference speed with TCS

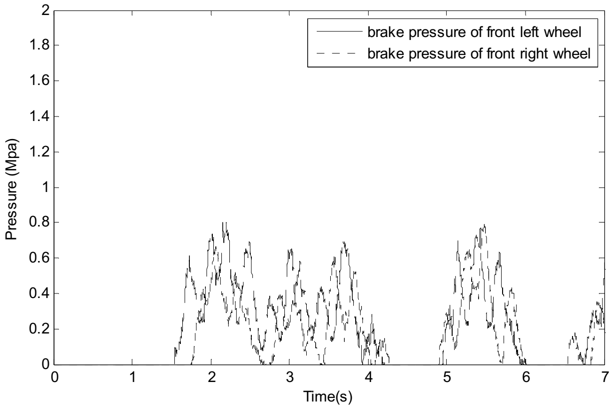

Fig. 8. Braking pressure during TCS control

As shown in figure 5, when driving off, both the left side and the right side driven wheel start to spin, this means that the engine output torque at the driven wheel, i.e. the drive force, is greater than the maximum force the ground can provide, so the engine throttle control decreased the opening amount engine throttle, as shown in figure 7. Besides, as the vehicle reference speed is low, so the braking controller of both driven wheels is triggered, as shown in figure 6. The speeds of driven wheels are controlled to their target values.

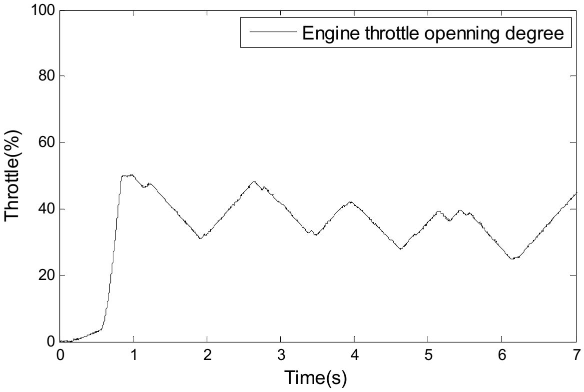

Fig.9. Engine throttle during TCS control

5. Conclusion

In order to validated the fuzzy PID traction control algorithm proposed, a HIL test bench based on xPC Target™ product of MATLAB® is introduced. The test bench consists of the hardware part and the software part, the hardware part is based on the xPC Target™ product of MATLAB®, the software part of the test bench, mainly the vehicle model, is created in Simulink. The validation of the proposed algorithm is implemented on the test bench and the results show that the spin of driven wheels can be controlled effectively and the acceleration performance can be improved when driving on slippery road.

References

[1] William Blythe, Terry D. Day: “Single Vehicle Wet Road Loss of Control: Effects of Tire Tread Depth and Placement”, SAE Paper No. 2002-01-0553, March 2002.

[2] Soo-Jin Lee and Young-Jun Kim, Kihong Park, Dong-Goo Kim “Development of Hardware-in-the-Loop Simulator and Vehicle Dynamic Model for Testing ABS” SAE Paper No. 2003-01-0858, March 2003.

[3] Huiyi Wang: “Hardware-in-the-loop Simulation for Traction Control the Debugs of its Electric Control Unit” SAE Paper No. 2004-01-2056, May 2004.

[4] Huiyi Wang, Bo Gao, Jian Song “Approach of debugging control laws of ABS combined with hardware-in-the-loop simulation and road experiment”. SAE Paper No. 2001-01-2729, November 2001.

[5] Liang Chu, Wanfeng Sun, Yong Fang, Mingli Shang, Jianhua Guo: “Development of a Test Bench for Integrative Evaluation of the Pneumatic ABS TCS Performance”. Vehicle Power and Propulsion Conference, 2009. VPPC '09. IEEE Press, Sept. 2009,pp.1079-1084, doi:10.1109/VPPC.2009.5289729

[6] Jianlong Zhang, Deling Chen and Chengliang Yin “Adaptive Fuzzy Controller for Hybrid Traction Control System based on Automatic Road Identification”. Proceeding of the 2006 IEEE International Conference on Automation Science and Engineering Shanghai, China, October 7-10, 2006, PP 524-529. Doi: 10.1109/COASE.2006.326936

[7] Jian Pei,LiMing Zhao, DeJun Wang and Liang Chu “Fuzzy PID control of traction system for vehicle ” Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, Guangzhou, 18-21 August 2005, pp. 774-777, Doi: 10.1109/ICMLC.2005.1527048.

[8] Quan-Zhong Yan, Faisal Oueslati, Jim Bielenda and John Hirshey: “Hardware in the Loop for a Dynamic Driving System Controller Testing and Validation” .SAE Paper No. 2005-01-1667, April 2005.

[9] Andreas Riedel and Alexander Schmidt: “Testing Control Systems of Trucks and Truck-Trailer-Combinations with Hardware in the Loop – Very Real Tests in a Virtual World” .SAE Paper No.2001-01-2768. November 2001.