

Systematic Approach in V-Model Development Cycle for an Automotive Embedded Control System

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Abstract

This paper focus, on the various stages involved in the development of automotive embedded control system. Various V-models (SIL, MIL, and HIL) are compared with the proposed V model for hydraulic Antilock Braking System. The various tools available at different levels of the V model development phase have been analyzed. Model in loop `discussed in detail and further steps involved in the HIL simulation process such as program design, module design, coding and testing phases are examined. The control system development is done using a development platform having a target- identical rapid control prototyping (RCP) system and can also be integrated with hardware-in-the loop simulation setup. This RCP system is designed very similarly to the real production controller with the help of a customized target package and hardware system.

Keywords: V-Model; Model in Loop simulation; Antilock braking system; Rapid Control Prototype.

1. Introduction

The electronic content within the vehicle continues to grow and more systems become intelligent through the addition of microcontroller based electronics. A typical vehicle today contains an average of 20-40 microcontrollers with some luxury vehicles containing up to 80 microcontrollers per vehicle. Flash-based microcontrollers are continuing to replace relays, switches, and traditional mechanical functions with higher-reliability components while reducing the cost and weight (Lean et al., 1999). The design and implementation of control algorithms is a crucial element in the

development of automotive control systems. One solution for optimization of the test process with respect to testing depth and incurred costs is application of automated testing in model-in-the-loop, software-in-the-loop, and hardware-in-the-loop simulations. In the last decade, researchers have enhanced the development process of the control system efficiently in both academia and industry. Isermann (1996) examined the importance of a systematic development process and software tools for the design. Hanselmann (1998) suggested that the modern development process is characterized by computer-aided support in all stages from specification to product. Smith (1999) also proposed that a more efficient development process is not intended to change the basic steps. Rather, improved software and hardware tools that can make the process more efficient. With the development of modeling and simulation software, model-based design approach has been widely promoted and greatly improves the efficiency of system development. Users can automatically generate embedded codes by RTW without manual programming. Some companies offer sophisticated development environments for automotive applications (Hanselmann, 1998; Leharth et al, 1998).

2. V Model Development Cycle

2.1 V Model

The major drawback of the traditional development processes is lacking with comprehensive tools, testing methods and the need for expensive prototypes. The modern development process provides an economical virtual test environment to minimize the expensive and time-consuming experiments, on the test bench or in-vehicle. At the beginning of a new project, the overall system specifications are collected. These requirements are analyzed and the core functions and features of each subsystem are specified. Control algorithms are primarily designed in response to the pre-defined specifications, and they are also made robust with respect to extreme and abnormal operating conditions. A modeling work of both the physical plant and the control system occurs in this stage.

2.2 Proposed V model

As in the case of modeling and simulation phase for an ABS controller, both the MIL (Model in loop) simulation and RCP (Rapid Control Prototyping) environment are used to represent the actual system as much as possible. With the help of RCP environment, the control engineers can easily validate and verify, integrated control system of their designed controller, in the vehicle or in special test benches. The next step is the modification of source codes to an appropriate form, for the production target processor and they should be tested against the functional requirements.

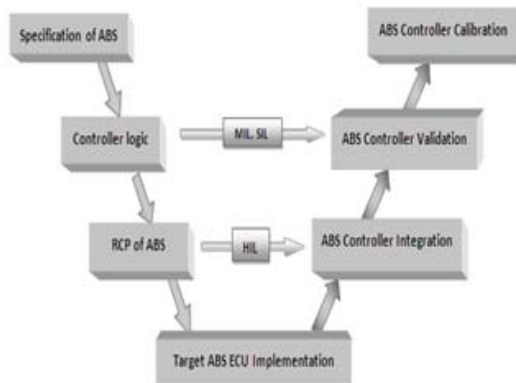


Figure 1: Proposed V-Model for ABS Controller

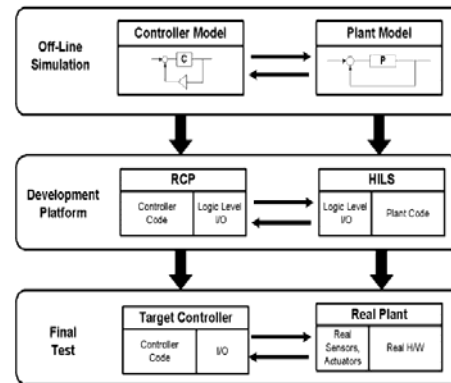


Figure 2: Integrated Development Platform

HIL (Hardware-in-loop) Simulation is characterized by the operation of real components in connection with real time simulated components. At the end of the design process, the control system is finally calibrated for the specific application using the HILs and the in-vehicle test procedures. The above mentioned process collectively forms a V model development cycle for Automotive Embedded control system.

3. Mathematical Modelling of Hydraulic ABS

A Typical ABS is composed of a central electronic unit, four speed sensors for four wheels respectively, and two or more hydraulic valves on the brake circuits. Most ABS-equipped cars are able to attain braking distances shorter than those without ABS. ABS will reduce their chances of crashing, and/or the severity of impact. Some ABS calibrations reduce this problem by slowing the cycling time, thus letting the wheels repeatedly briefly lock and unlock. The primary benefit of ABS on such surfaces is to increase the ability of the driver to maintain control of the vehicle rather than go into a skid— though loss of control remains more likely on soft surfaces like gravel or slippery surfaces like snow or ice.

The wheel rotates with an initial angular speed that corresponds to the vehicle speed before the brakes are applied.

$$\omega_v = V_v / R_r \quad (1)$$

$$\text{slip} = 1 - (\omega_w / \omega_v) \quad (2)$$

ω_v – Vehicle Speed divided by wheel radius

V_v - Vehicle linear velocity

R_r - Wheel Radius

ω_w - Wheel angular Velocity

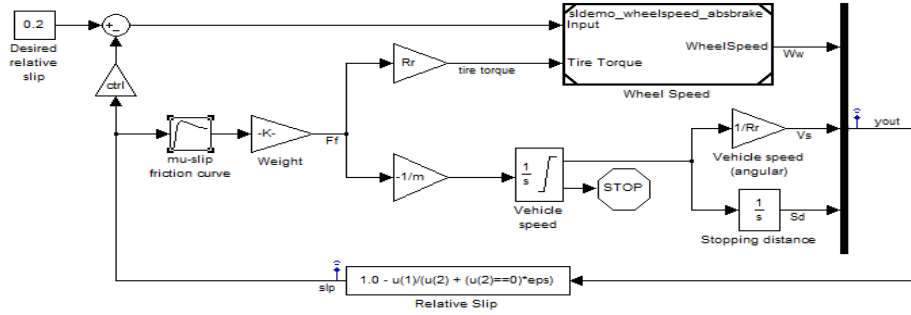


Figure 3: Simulink Model of ABS Plant.

From above slip is zero when ω_v and ω_w are equal, and slip equals one when the wheel is locked. A desirable slip value of 0.2 maximizes the adhesion between the tire and road and minimizes the stopping distance with the available friction. From measuring the ω_v and ω_w the slip of each wheel is calculated. The friction coefficient between the tire and the road surface, μ is an empirical function of slip, known as the mu-slip curve.

$$F_f = K \times \mu \quad (3)$$

F_f = Frictional Force on a Wheel

μ - Coefficient of friction calibrated from mu-slip curve which is modeled as a Lookup Table

K - Weight of one wheel

$$d^2 S_d / dt^2 = - F_f / m \quad (4)$$

From the equation (4) Stopping distance (S_d) and vehicle Speed is calculated in the model.

$$\text{Tire Torque} = F_f \times R_r \quad (5)$$

R_r - Radius of a Wheel.

In this model, an ideal anti-lock braking controller, that uses 'bang-bang' control is designed, based upon the error, between actual slip and desired slip. The Hydraulic actuator used in braking System is represented as hydraulic lag transfer function. It takes slip as input and calibrates the amount of change in pressure, needed for braking.

$$d\omega_w/dt = (\text{Tire Torque} - \text{Brake Torque}) / \text{Mass moment of Inertia of a wheel (I)} \quad (6)$$

Integrating equation (6) wheel speed is calculated.

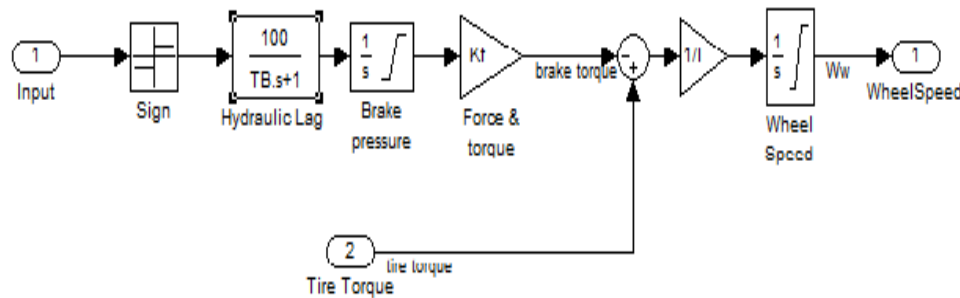


Figure 4: Simulink Model of ABS Controller on single wheel.

4. Result and Discussion

The model based functional verification of a hydraulic braking system under the action of an ABS controller is discussed. The bang-bang controller used here cannot be used for road surface with different coefficient of friction. For a hardware-in-loop simulation of a braking system, target code is generated and compiled for the controller hardware, to test run the equations of motion on real-time hardware to emulate the wheel and vehicle dynamics. This significantly reduces the time needed to prove new ideas by enabling actual testing early in the development cycle.

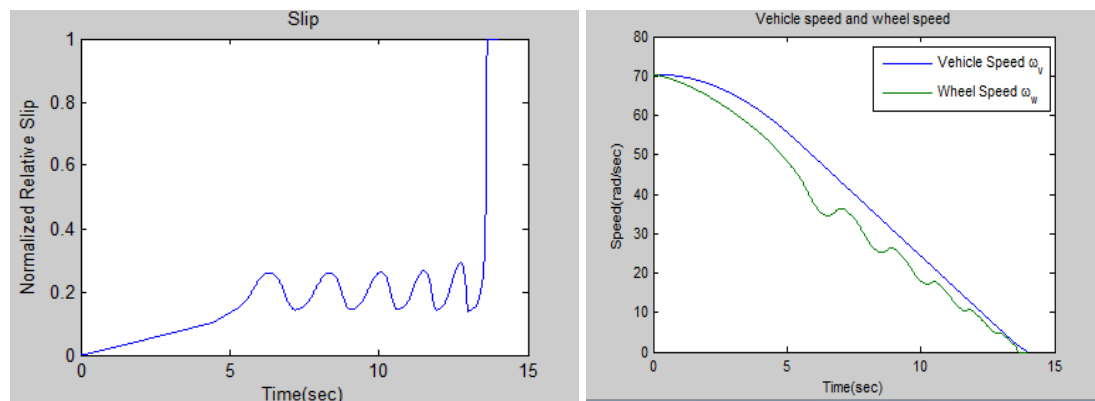


Figure 5: Relative Slip Vs Time and wheel, vehicle speed Vs Time

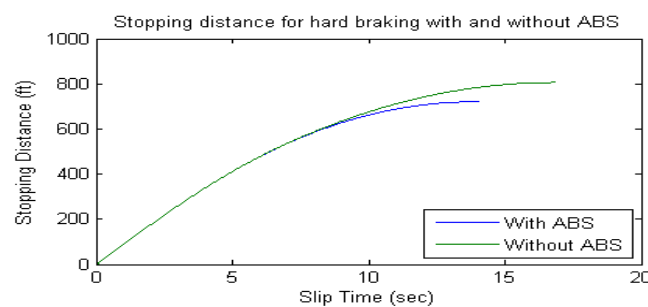


Figure 6: Slip Time Vs Stopping Distance.

5. Conclusion

A new development platform for automotive Hydraulic braking system is introduced. MATLAB/SIMULINK–Real Time Workshop tool-chain is used as a base environment for implementation and evaluation of the ABS controller as well as the development of the control algorithm. This platform provides a target-identical RCP platform and PC-based HILs environment. With the help of a customized target package and the advent of powerful microcontrollers, the RCP system is organized very similar to the real production ECU. This feature alleviates many implementation problems, which may occur between the RCP system and the production system. The control system is easily investigated and validated using the PC-based HILs system. The simulation results show that the proposed development process and the virtual experiment environment can efficiently handle various ECU design problems caused by transitions among separate development steps. The proposed environment can be a basis for the model-based approach in Anti locking braking system.

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