Model Based Embedded System Development for Automotive Application

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***Abstract*— Electronic content within the automotive continues to raise and systems becoming more intellectual. Automotive systems are comprehensively interactive, diverse, and multi-disciplinary by nature. In order to participate effectively in the automotive industry, vehicle manufacturers employ cutting-edge and innovative techniques in their product development. We proposed a flow, on the various stages involved in the development of automotive embedded system. Also focus on the different integrating environments and tools needed for modeling and simulation of sub-components at each abstraction level such as, Model in Loop, Software in Loop, and Hardware in Loop. Our flow has been tested for use case like Heat Ventilation and Air Conditioning system in car. In this paper, we presented three-phase verification process (MiL, SiL, HiL) to verify the functionality of HVAC systems. Such verification platform provides a flexible simulated testing environment which allows synchronization among the real and simulated world.**

***Index Terms*— Electronic Control Unit (ECU), Hardware in the Loop (HiL), Heat Ventilation and Air Conditioning (HVAC), Model in the Loop (MiL), Software in the Loop (SiL).**

I. INTRODUCTION

The automotive industry is extremely competitive and vehicle manufacturers are facing the constant challenge of meeting increasingly short development times whilst sustaining a high standard of quality and safety. To satisfy the ever increasing requirements for safety, comfort, and environment protection of today's vehicles, the Electronic Control Units (ECU) and several sensors are getting more and more complex, hence complication of modern vehicles has increased greatly in recent years with electrical/electronic systems replacing many traditionally mechanical and pneumatic systems and providing new technologies for the user. A typical vehicle contains more than 100 Electronic Control Units [5]. Now, the design and implementation of control algorithms against requirements and specification is a critical element in the development of automotive embedded systems [1].

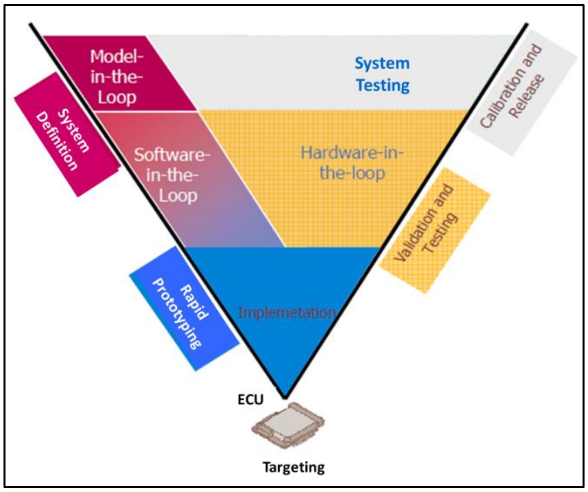

Figure 1 V-Model development process adopted in this paper

Therefore, developing new control algorithms and cost effective verification tools for a new generation of ECUs and sensors has become a highly important concern [1]. This reference also deals with the design and implementation of a versatile automated HIL test environment, which facilitates the development of control algorithms, calibration, and verification of state of the art sensors and ECUs. The environment is able to emulate the vehicles' dynamic behavior, reduces the time required for development and testing, and eliminates the need for using expensive real vehicles for testing purposes. Some existing verification and test systems are available from various manufacturers like dSpace, ETAS, National Instruments, Systerra, etc. These systems are suitable for special tasks such as development or verification of a specific sensor and ECU.

Integration of testing, debugging, and process simulation tools is necessary for software verification against vehicle models. Solution for such optimization of the test process with respect to testing depth and acquired costs is application of automated testing in model in-the-loop, software in-the-loop, and hardware in-the-loop simulations [2].

In this paper, we proposed a flow to demonstrate all development phases of ECU. We used HVAC as a use case and for this we developed controller functionality of HVAC. The overall flow is applied to ensure verification of requirements and system and software design, which follows figure no. 1, the iterative V-Model development process.

II. HVAC SYSTEM DESCRIPTION

HVAC is a complex mechatronic system in a modern vehicle. It consists, especially in high end vehicles, with high number of distributed mechatronic actuators and sensors and a central controller. The aim of these systems is to achieve a desired climatic condition in the vehicle compartment which leads to comfort for the passengers and therefore indirectly it also increases the safety in road traffic [4]. The climatic condition is defined by the internal temperature, external temperature, the velocity of the airflow blowing through the passenger compartment and the humidity (Humidity part is not considered in our scope). Also sun intensity and its radiations disturb the internal temperature. Modern automatic HVAC systems are equipped with a large variety of sensors and actuators to handle this complex control task. To create the desired interior climate, a good knowledge of the operating mode and the behavior of the entire air conditioning system including the passenger compartment are necessary to apply sophisticated open and closed loop control strategies. The interrelations of the controller, various subsystems of HVAC and the environment are shown for a general modern auto heat ventilation and air conditioning system in figure 2.

The shown subsystems are strongly coupled and therefore a desired but also parasitic interaction exists between these units. As these systems' becoming more complex, more effort has to be invested to any ensure consistent demands towards safety, dependability, and availability of the system. This requires a more structured and efficient development and verification processes like V-cycle which is discussed in next section.

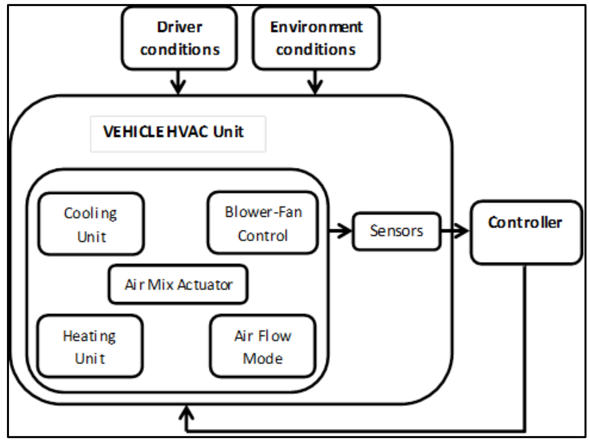

Figure 2 Interactions between the vehicle, environment, driver and air conditioning system's controller

III. VERIFICATION FLOW

A three-phase verification process is devised and proposed to be applied on the chosen model (the control algorithm model in our case) and the chosen ECU. Figure 2 shows the three phases considered here and their interactions.

The first phase is intended for modeling sub-systems, such as control algorithms called as Model-in-the-Loop-Simulation (MIL-Simulation). It is an exclusive virtual simulation, where the interaction of only continuous models of all subsystems is simulated. Control algorithms, which are subject to early verification, are modeled using tools such as Matlab/Simulink. Then, simulation and test execution verify the model before proceeding towards the development process. This modeled control algorithm is then converted into suitable code for target controller, where the conversion can do manually or through automatic code generation of Simulink.

The next step is the Software-in-the-Loop-Simulation (SIL-Simulation). Its main aim is the simulation of the software realization of the controller against its high-level abstracted model, and other system parts with logic in interaction with the control path. Here the sampling times of controllers and discretization effects occur and take effect on the simulation. This environment provides a verification approach for target code correctness by porting the code, also provides editors or generators for designing the target description resources.

The third and last-one simulation method in this chain is the Hardware-in-the-Loop-Simulation (HIL-Simulation). HIL simulation aids real-time simulation in which the simulated plant is tied with an actual system under test (SUT) in a manner similar to the real-world. HiL verification involves integrating ECUs with the process (i.e., sensors, actuators, and plants), whether it is real or virtual, and modeled environments/surroundings. For example a controller is coupled under use of suitable mechatronic interfaces (mechanical, electrical and also information processing interfaces) with virtual system parts that are simulated by models on one or more real time computers. If HIL simulation step is implemented successfully, the simulation is followed by a normal test where all system parts are obtainable in their final form. In case of the air conditioning system this test is usually a trial run under several conditions in a vehicle prototype.

IV. HVAC VERIFICATION PHASES

What HVAC actually does is described in section II. The main focus of HVAC is to provide the cabin comfort for passengers. This section deals with the various verification phases of use case.

A. Function Development

Typically building control software to interact with a mechatronic system is nothing but controller model development or control systems development. These are referred to as the "controller" and the "plant". Functioning of ECU is depends on the controller model algorithms made by developer. Plant model is used to models the environment so the ECU software can operate the way it would on a real vehicle.

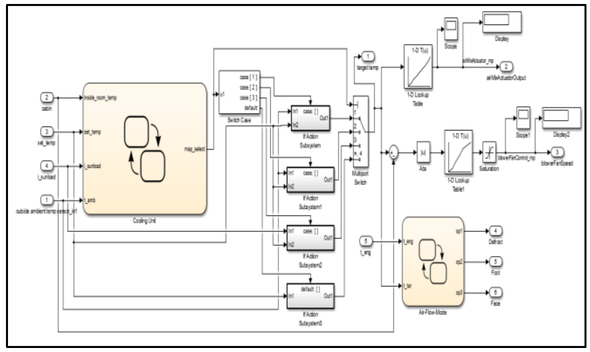

Figure 3 HVAC Controller Model in MATLAB/SIMULINK

Our proposed verification methodology starts by a simulation of the model for the HVAC controller and plant algorithms as shown in fig 3 and 5 respectively. At the first phase, it is important to verify design functionality, tune the controller, to achieve a certain closed-loop performance. Here, the controller and plant model is developed in MATLAB/Simulink. For manual testing of controller, we developed some test cases as shown in Table I, with the results.

Table I. MIL Phase results

T_amb	T_cab	T_req	I_snload	T_tar	Blower_fan	Air_flow_mode
30	30	28	100	28	14	011
40	30	28	100	26	18	011
30	30	28	1400	25	20	011
30	5	28	100	28	85.7	011

In the manual testing of controller, we taken different values of cabin temperature, ambient temperature, set temperature, sun-load intensity.

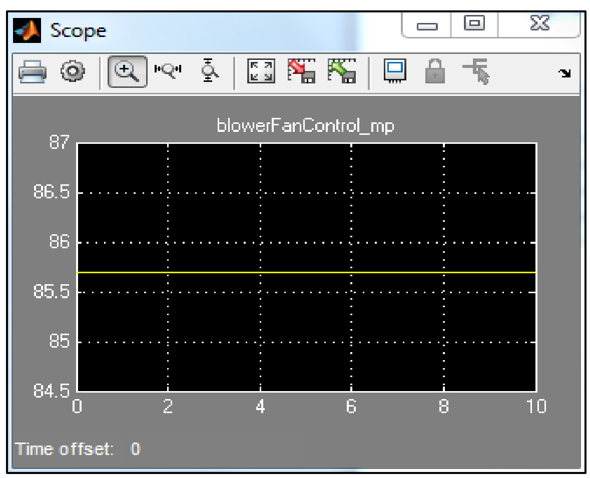

Figure 4 Blower Fan’s Simulink Result for the last Test Case mentioned in Table I

Depending on the all values and assumptions made for algorithms, we checked the values of target temperature, blower fan and air flow mode. The result is figured in table I. Simulink graph of blower fan control for last test case (mentioned in table I) is shown in figure 4.

Plant model also checked against controller functionality. As per the assumptions made for plant model cabin temperature should increase or decrease with respect to target temperature. It should stop increase or decrease cabin temperature when it reaches near to the target temperature. The result of increase in cabin temp with respect to time is shown in figure 6. Here cabin temperature is settled after reaching the target value.

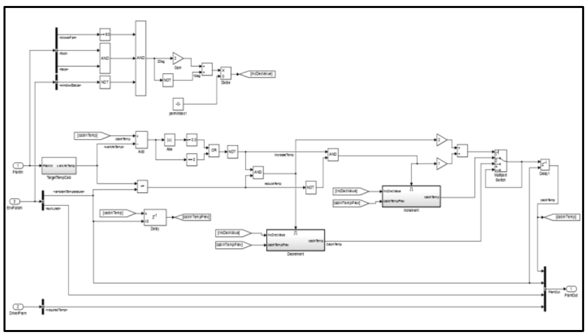

Figure 5 HVAC Plant Model in MATLAB/SIMULINK

B. Prototyping

Once the controller model functionality are tested, they are converted into A2L file which is ready for flashing into the rapid prototyping target (target may be any scalable and open architecture ECU or hardware).

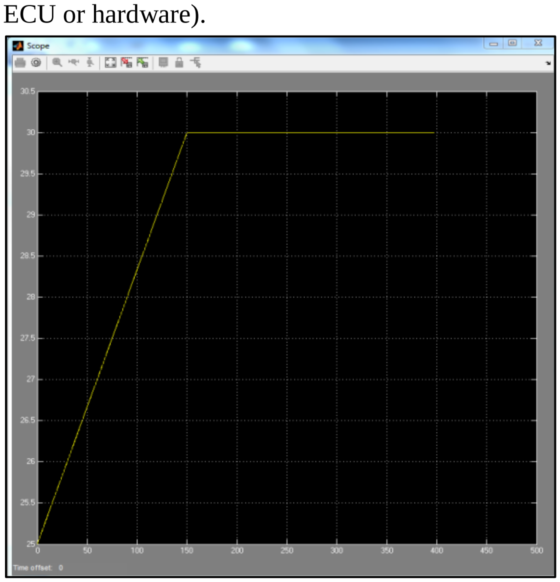

Figure 6 Graph for the output temperature

C. Test and Validation

The engineer moves to comprehensive testing like HIL where even dangerous situations can be tested safely. For HIL simulation plant model is needed. Plant model simulates driver, vehicle and environment so that the functionality of the ECU can be tested as if it were in a real vehicle.

The HIL simulator has a modular architecture and can easily be reconfigured for different projects. The general architecture of HIL simulator is shown in figure 7. Almost the whole development and test process can be performed on the same system, from the design of new algorithms to the HIL tests.

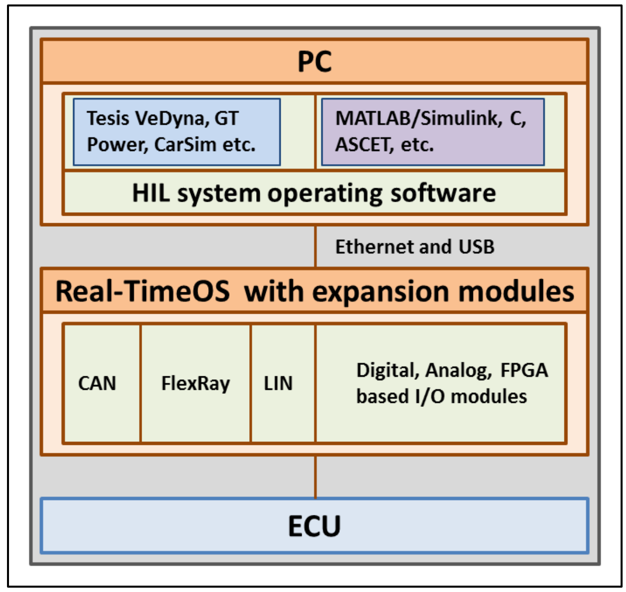

Figure 7 General Hardware in Loop Simulation architecture

The hardware architecture consists of three main parts. They are as follows:

1. A standard high performance industrial computer;
2. A real-time system with reconfigurable I/O module and communication interfaces. Module may be digital, analog or field-programmable gate array (FPGA) based; and
3. Target ECU.

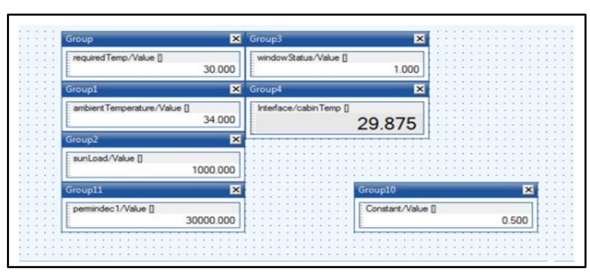

Figure 8 HIL system result

The Windows-based high performance computer (PC) does not have any special interfaces. It provides the software environment for modeling vehicle dynamics and for creating test maneuvers. On the real-time controller, a real-time operating system (Linux) can be run which provides the run-time environment for Plant model. It also has several interfaces such as CAN, FlexRay, LIN and cards for digital and analog I/O. Some cards are FPGA based and great advantage of these cards is that there are a lot of predefined programs for various functionalities like signal conditioning, filtering, Pulse-Width Modulation (PWM) generation, etc. ECU holds the control algorithm while Real Time OS holds the plant model.

After successful configuration of plant and controller we got some results with HIL system as shown in figure 8. In our system controller output goes to plant as an input and plant output goes to controller as an input to achieve closed loop functionality.

V. CONCLUSION

As we developed a demo, the results have shown that with simplified models for the HIL-Simulation but it is possible to simulate the complex vehicle interior air conditioning system. Because of the model simplicity a lot of used parameters cannot be derived in an easy way from fundamental relations. Therefore it is necessary to determine them from detailed simulations or measurements at the real system.

For the future a further model verification for the HVAC in interaction with the passenger compartment model and a broad variety of different weather as well as driving conditions have to be carried out.

As a conclusion, we can state that a powerful reconfigurable HIL simulation and test environment was designed with respect to hardware and software architecture. The elaborated new system is suitable for long-term hardware maintenance and easy software migration from the old systems, and according to the measurements, it was proved that it is a good alternative to existing automotive simulation environments.

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