

Evaluation and Design of Electric/Electronic-Architectures of the Electric Vehicle

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ABSTRACT

The evaluation of electric vehicle electric/electronic-architectures (e/e-architectures) is the main topic of this paper. The electric vehicle is chosen as an example system, as it reflects the typical challenges of modern vehicle e/e-architecture development. The development of modern automotive technology also presents another important trend - vehicle electrification. New electric and electronic devices are developed and required in the automotive industry and control commands are exchanged by electric and electronic ones. The energy storage systems (ESS) properly reflect the above two aspects. The energy storage device also takes care of the peak loads, the high load dynamics, and it utilizes the braking energy in order to increase the efficiency. In this work a Li-ion battery and an ultracapacitor both are considered as energy storage devices. The ESS is designed in an iterative process under a driving cycle where the power flow through the vehicle is under the influence of a certain energy management strategy, which steadily and rapidly divides the power between the units.

In this paper, a distributed e/e-architecture with a vehicle control unit is modeling. In the early development phase, there is quite a big degree of freedom in the allocation of function components to ECUs. Multiple objectives, like costs, weight or busload, have to be considered for optimizing the allocation. Moreover, an ant colony optimization (ACO) is introduced supporting a multi-objective optimization of the allocation. The new architecture facilitates the information exchange, minimizes the cost and effort of vehicle harness, and reserves the configurability and expandability.

To support the design of e/e-architecture, the platform to simulate and compute electric vehicle dynamics and driving distance is critically important and useful. At last, it presents such a simulator, which consists of core components such as the power driven system and vehicle stability control systems. Moreover, concrete use cases of this simulator are given, which assess electric vehicle performance according to different functional and ESS hardware architectures.

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INTRODUCTION

Nowadays, the number of electronic control functions in mass-produced vehicles is continuously increasing. Especially, stability control systems are becoming standard. Augmentation of the number of integrated control functions makes vehicle development more and more complicated. Nevertheless, the vehicle is not increased time to market despite the increasing intersystem complexity [1].

However, during the vehicle development phases, problems of compatibility among embedded control units (ECUs) may appear, requesting rapid modifications in the final stage. For instance, ignoring to compensate a delay generated by a gateway between the embedded control unit (ECU) of the ACC controller and the EHB controller, the vehicle could crash into the car ahead. To avoid the

above situation, the controller should be updated, eventually requesting another control algorithm. It should be calibrated, tested, verification etc. Above mentioned problems are mostly prevented during virtual integration in the Hardware-in-the-Loop (HIL) [2]. Thus, they are increasing the cost and causing the product is not stable. Moreover, HIL allows for the testing of a given control system over a much broader range under extreme conditions than real prototyping [3].

The above problems can be avoided through perfection of the development process of the e/e-architectures, by optimizing a functional architecture at the early stage of the project, between the product requirement specification and the vehicle design phases [4].

The e/e-architectures realize the function of most of modern vehicles. The e/e components and networking makes some new functions coming true, such as, vehicle information system and driver assistance system [5]. This architecture integrally defines the needs of each vehicle function, in terms of inputs, outputs, and algorithm specifications. After the design of the function architectures, the functions allocation describes the hardware components that must be installed to the vehicle, such as the set of sensors, actuators, ECUs, and the bus communication systems. Last, the designers of the physical architecture can arrange these components in the vehicle and design the wiring harness.

Two kinds of model are defined in this e/e-architecture, which is shown in the Figure 1. The demand model describes the realization of the function in the abstract level, namely it is independent of realizing the function of the hardware. The actual model determines the functionality used e/e components and distributes relating hardware for the functions [6].

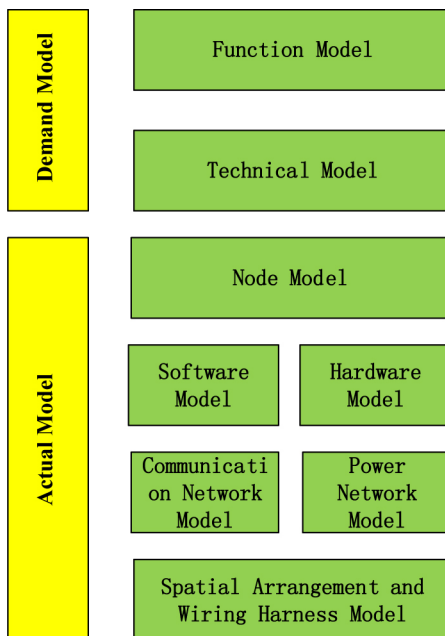


Figure 1. e/e-architecture model.

To achieve optimization architectures, preconditions have to be fulfilled. One of these preconditions is the ability to evaluate the optimized systems, in the established architectures. This is the first step for the evaluation of e/e-architectures. In the present paper this knowledge is used and represented in a chosen evaluation method. At this point an introduction to e/e-architectures of electric vehicles is given, such as electronic control systems and energy storage systems. In the following sections a chosen method is applied to the use-case.

With the knowledge of mapping functions on different hardware within the electronic architecture, the optimal allocation is adopted considering different objectives and constraints. This paper presents optimization algorithms that can be applied in order to find an optimal function allocation. State of the art ant colony optimization algorithms have already been shown.

To be able to perform such a functional approach, we have developed an iterative process, aiming at assessing the functional and physical architecture through a vehicle simulator, as shown in Figure 2. Moreover, for example, the communication latency time between two components of a function is concretely tested on a first virtual prototype for verifying the control performance [7]-[8]. They are ongoing in the automotive domain, with the functional development proposed by Autosar, and already available in some tools, or the commercialization of programs linking the functional description with the simulation or implementation tools.

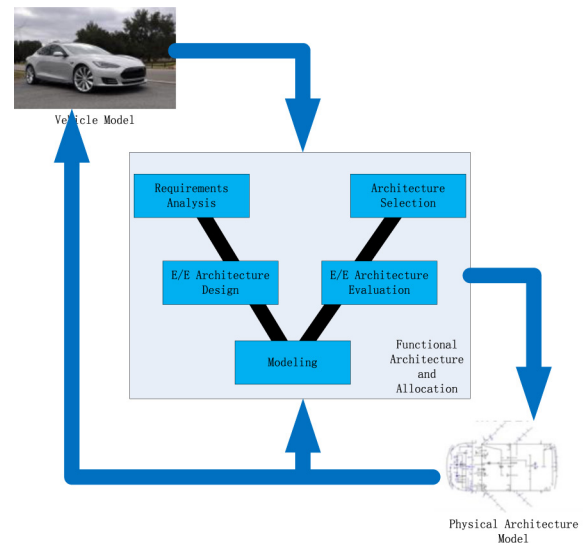


Figure 2. Development process for an electric vehicle e/e architecture.

In this paper, the chosen evaluation method is described in detail, which is a contribution to the optimization of e/e-architectures. As a big degree of freedom in the allocation of electronic components to ECUs, multiple objectives, like costs, weight or busload, have to be considered for optimizing the allocation. Finally, a concrete example of using the simulator is provided, verifying the performance and reliability. It describes a simulator that has been developed to improve the vehicle architecture, by focusing on the implemented models of the main vehicle components, such as the ESS and the electronic stability controller (ESC). According to the state of the art, the main advantage of this simulator is to take benefits of two existing platforms, namely, MATLAB/Simulink, which allows the easy prototyping and implementation of a dynamic module, and Advisor, which allows electric driving modeling.

ELECTRIC AND ELECTRONIC-ARCHITECTURES MODELING OF THE ELECTRIC VEHICLE

The e/e-architectures model of the electric vehicle is composed of three separate components, namely the communication signal network (CSN), to which all in-vehicle electric/electronic units (EEUs), from a single light to the complex vehicle control unit, are connected directly; the energy supply network (ESN), from which all EEUs obtain a stable energy supply; and the electric drive network

(EDN), which ensure the electric vehicle power performance and driving distance. The electric vehicle architecture is sketched in Figure 3.

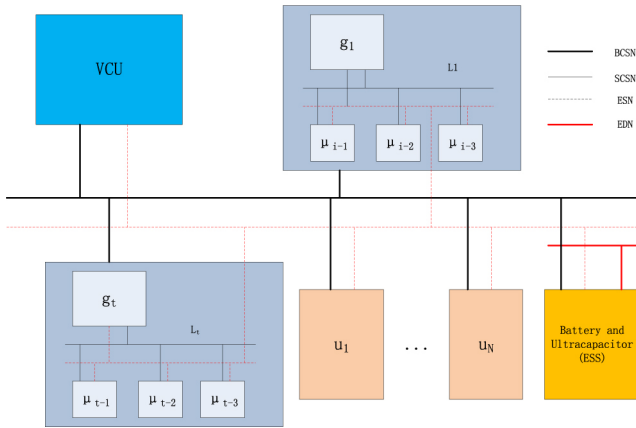


Figure 3. The electric vehicle e/e-architectures.

The architecture EEA can be expressed as

$$EEA = \{B, S, E, P\} \quad (1)$$

where

B =backbone communication signal network (BCSN) set;

S =subnet communication signal networks (SCSN) set;

E =ESN set;

P = energy storage systems set in the EDN.

As shown in Figure 3, all the EEUs presented in the electric vehicle are exchanging data with a network communication interface. The CSN connects all the EEUs, which features a hierarchy structure with network sets B and S . The EEUs in S exchange data with EEUs in B through the gateways. The hierarchy structure simplifies the topology and harness route design, and lowers the overall cost of the e/e-architectures. Energy storage systems in the EDN ensure the electric vehicle dynamics and reliability.

A dedicated energy network E (ESN in Figure 3) is introduced in the e/e-architectures, which is responsible for the energy supply for all the EEUs. The EDN provides acceleration power demand and energy demand of drive distance and implements the vehicle reliability.

Configuration of the Distributed CSN

The CSN is a hierarchy composition of the BCSN B and SCSN S . The BCSN B can be expressed as

$$B = (b_c, U) \quad (2)$$

where

b_c =backbone bus harness, e.g. CAN wirings;

U =backbone EEUs.

There are multiple SCSNs S_j . The set S can be expressed as:

$$S = \{S_j | j = 1, 2, \dots, M\} \quad (3)$$

where

$$S_j = (b_j, \Delta_j) \quad (4)$$

$$\Delta_j = \{u_{jl} | l = 1, 2, \dots, m(j)\} \quad (5)$$

where

b_j =subnet bus harness, e.g. LIN wiring;

Δ_j =subnet EEUs;

$m(j)$ =number of EEUs in Δ_j .

The gateway g_j , which serves as the message relay and filter between B and S , are defined as virtual compound EEUs in B , which can be expressed as:

$$\hat{d}_j = (g_j, S_j) \quad (6)$$

Configuration of the Distributed ESN

The in-vehicle controller energy requires the low voltage (LV) electronics consumers, typically 12 V. The ESN in the e/e-architectures is expressed as

$$E_l = (e_l, e_g) \quad (7)$$

where

e_l = LV energy;

e_g =ground for e_l .

The configuration of EDN is modeling in the following sections.