A New Validation Concept for Globally Distributed Multidisciplinary Product Development

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Abstract Developing electric vehicles is very important in reducing greenhouse gas (GHG). Since one of the main changes in automotive industry is the entry of new disciplines, the development of electric vehicle as a multidisciplinary product requires more and closer cooperation between company departments at different locations, for example between OEMs and globally distributed suppliers.

For supporting the multidisciplinary product development like mentioned above, IPEK has implemented a new validation concept for globally distributed product development based on its X-in-the-Loop-Framework. The "X" is the substitution for the Unit Under Test (UUT) which is validated under consideration of the influences from the rest system, user and environmental situations. The new validation concept is characterized by a "distance loop", which means the UUT and other elements could be located across the facility or even the globe.

The advantages of the new validation concept are demonstrated in this paper with a concrete application example.

Keywords Distance loop • Multidisciplinary product development • Validation • X-in-the-loop

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1 Introduction

Developing and establishment of electric vehicle is considered to be an important step towards reducing petroleum dependence, protecting the environment, and improving transportation sustainability. Germany and China are both leaders in the area of electric automotive industry. On request of ministry of science and technology of both countries (BMBF and MOST[1]), a couple of cooperation projects in this area are established between German and Chinese universities. One focus of these projects is set on development methods of electric vehicles. In order to grasp the current used development methods and expected changes in automotive industry a few experts from automotive OEMs, suppliers as well as Start-Ups in Germany and in China were interviewed. According to the interviews, one of the main changes in future automotive development is the entry of new disciplines in automotive industry. In addition location-dependent influencing factors have an increasing significance due to different driver types and environmental situations which have to be considered focusing the target market. These all lead to more and closer cooperation between globally distributed company departments.

Corresponding to the fundamental changes of powertrain systems and development environment, appropriate changes to existing development methods in automotive industry are needed. Validation as the central activity of product development process (Albers et al. 2011) stays in the focus. For this purpose, the IPEK X-in-the-Loop-Framework (Albers and Dueser 2010) has been expanded to "distance loop". In this case different sub-systems at different locations can be validated under consideration of interrelating influences by realizing a remote but in-time configurable validation without relocating the UUT or any other element of the X-in-the-Loop-Framework. Additionally the UUT can be validated under control of any user and in any environmental situation. Therefore this validation concept facilitates closer and better cooperation between departments at different locations and enables a better consideration of market-specific influences for example driver behavior or environmental situations.

The related research of the new validation concept is introduced in the following chapters.

2 Methodology

Validation defines the continuous refinement of the system of objectives and the product's success by continuous comparison with the achieved system of objects (Albers et al. 2011). It's the only way to check the fulfillment state of the customer's

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objectives and only through validation can knowledge be gained (Albers et al. 2011). Validation is the only activity in product engineering that generates information, insight and knowledge (Albers et al. 2011).

Since its importance in product development, the focus of the following chapters is set on the continuous validation activities.

The development and validation of a multidisciplinary product like an electric vehicle comprises a lot of challenges due to the continuously increasing complexity in different areas of conflict. First of all aspects like NVH and driveability, abrasion and durability, energy efficiency, travel range, costs and safety must be considered at the same time. The second area of conflict is related to operation systems, which have to deal with many established and available tools and methods for application, simulation, optimization, testing and rating, which are only partially cross-linked. Furthermore new advanced systems development approaches are required to consider the three complex interacting systems driver, vehicle and environment (Albers et al. 2010). The driver and the environment are the characters of target market and have very important influences for future operating and driving strategies. In order to successfully take up these challenges, the X-in-the-loop Framework has been developed, implemented and advanced at the IPEK.

The IPEK X-in-the-loop-Framework represents a holistic and integrated validation framework (Albers and Dueser 2010). The "X" is the substitution for the Unit Under Test (UUT). Compared to the established Hardware-in-the-loop (Brendecke and Küçükay 2002) approach the UUT can be a virtual prototype (Albers et al. 2008a) or a physical prototype (starting from working surface pair (Albers et al. 2008b) e.g. friction facing up to the complete vehicle). This causes different layers in the XiL-Framework: the element-in-the-loop-, the subsystem-in-the-loop- and the vehicle-in-the-loop-layer (Albers et al. 2008a) (Fig. 1).

On each layer the rest vehicle is simulated and always connected to the driver and the environment in order to be able to realize loads on the UUT, which are comparable with the loads in the physical application. There are different levels of the driver, the environment and the rest vehicle simulation, which have to be chosen in context of the application and development task. In the XiL-Framework it is possible to execute open- and closed-loop tests on each layer. So it is always possible to analyze the influences of driver behavior and environmental situations. These aspects are very important for the future vehicle development with focus on the target markets, e.g. for the development of different driving- and operating strategies, safety systems and powertrain calibration specific for each target market (Albers et al. 2008b).

Usually when performed experimentally all elements of the XiL-Framework are located in one test lab, in order to simply connecting the different systems. A concrete application is the IPEK acoustic roller test bench with integration of a driving simulator (Fig. 2). In this case the UUT (mostly the whole vehicle) is connected via CAN cable with a real time system, in which the rest system model and the virtual environment are simulated. The driver could be a driver model, which runs in the real time system or a real driver on the driving simulator, which is also connected with the real time system.

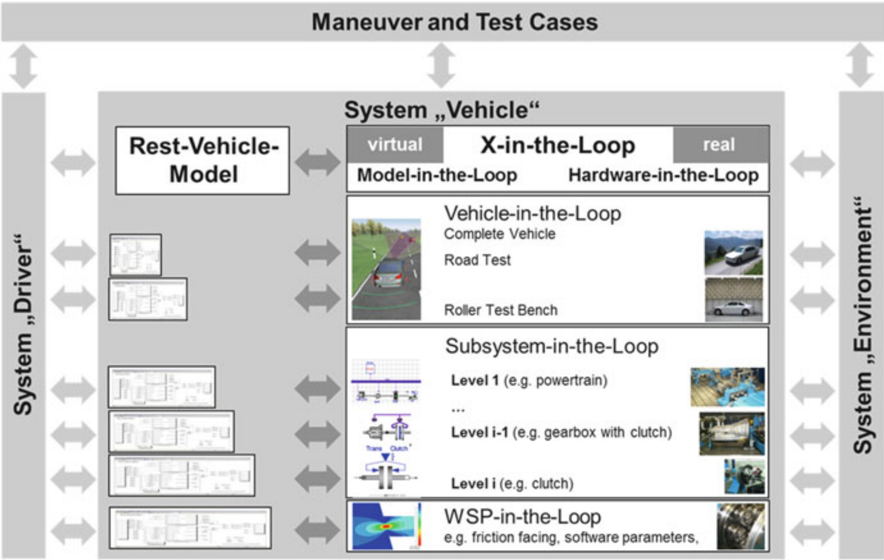

Fig. 1 IPEK X-in-the-Loop-Framework (Albers et al. 2008b)

Fig. 2 IPEK acoustic roller test bench with integration of a driving simulator

However the UUT is developed and produced somewhere else around the globe very often and therefore it has to be transported to the test lab, it takes always time and cost. Furthermore the in-time-optimization of the UUT can hardly be realized during the validation process, since not all the test engineers in the test labs have the appropriate knowledge about the UUT and its interrelations, especially in the multidisciplinary product development.

One important advantage of the XiL-Framework is the possibility to validate the developed models or prototypes in the early phase of the product development process like in design phase under comprehensive consideration of the influences from user and environment. Due to that, the new developed models or prototypes are mostly confidential and the enterprises do not always gladly publish them. This restricts the multidisciplinary product development, which requires close cooperation between enterprises like OEMs and suppliers.

To meet these challenges the IPEK XiL-Framework has been expanded with a new validation concept. The new validation concept is characterized by a "distance loop", which means the UUT and other elements could be located at different areas across the globe. Principally the software and hardware architecture can be defined as usual, only the real-time capable data transfer has to be extra realized and the required information for both sides should be defined from the engineers and testers together.

Based on the new validation concept some validation platforms can be imagined. For example the UUT stays in the place of production (e.g. suppliers) under consideration of its engineers and is connected via internet with the other elements of the XiL-Framework like the rest vehicle model (e.g. from an OEM). Therewith it is possible to validate the systems from suppliers under consideration of specific influences from the vehicle without releasing confidential vehicle models etc. Hence, this validation platform saves time and cost for transportation, avoids the confidential problem and realizes the in-time-modification and -optimization of the UUT. Describing another example, the system "driver" could be a customer, who sits on a driving simulator in another place (e.g. subsidiary company in the target market) and "drives" the UUT which is located in the test lab of the manufacturer (e.g. parent company). Thus the platform enables the consideration of market-specific influences even in the early phase of development.

The new validation concept was implemented in an application example of subsystem-in-the-distance loop. The main purpose of this application is, to validate the applicability of the new validation concept. Therefore the problem was scaled down in order to save time and cost. Thus the in-wheel-motor of an electric vehicle was represented by a small e-motor. This small e-motor was investigated on a remote test bench and connected via internet with the rest vehicle model, the system "environment" and the system "driver". The system "driver" has been presented in two concretization degrees respectively virtually and physically. The Fig. 3 below illustrates the validation setup of this application.

In the following, each element of this application is briefly described.

The remote test bench is the IPEK Mini-HiL (Zimmermann et al. 2009). The IPEK Mini-HiL is built as a development environment for testing new test bench configurations and developing ideal control strategies before they are implemented on the more powerful test benches. It enables simply and quickly validation due to its compact modular construction. Like most test benches in the area of drive engineering, the Mini-HiL has two e-motors, a drive motor and a driven motor (Zimmermann et al. 2009). In this application the drive motor represents the

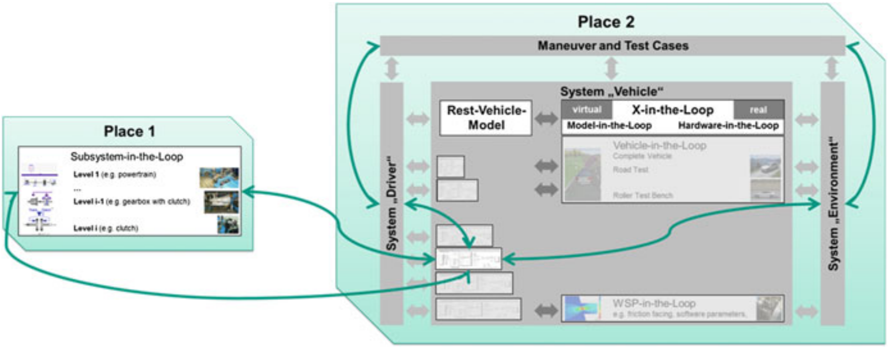

Fig. 3 Application setup

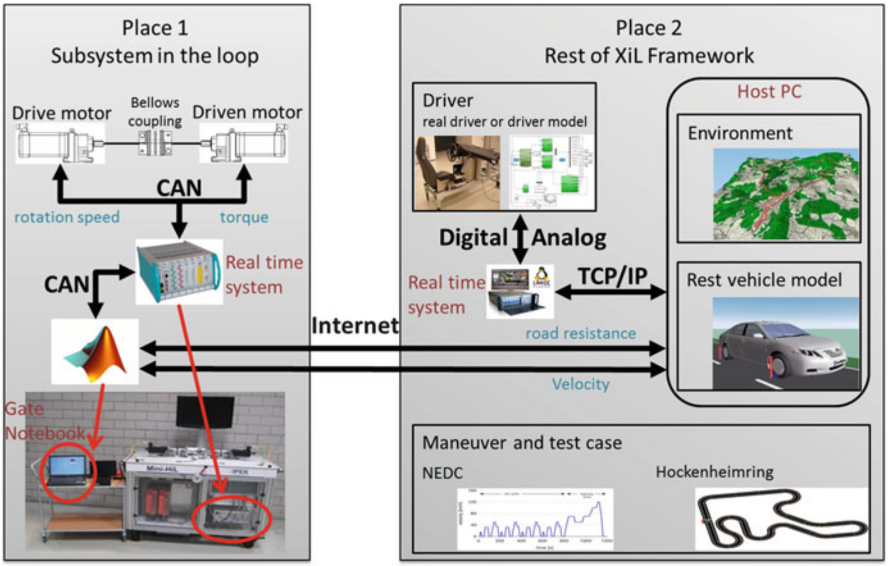

Fig. 4 Hard- and software architecture

in-wheel-motor of an electric vehicle as the UUT. It receives the set rotation speed from the rest vehicle model. The driven motor is connected through bellows coupling with the drive motor; it receives the set torque and provides the road resistances.

The notebook beside the Mini-HiL (see Fig. 4) works as a gate between the remote test bench and other elements. It receives vehicle velocity and road resistance from the rest vehicle model converts and sends them as set rotation speed and torque to the Mini-HiL. In the opposite direction it receives the actual rotation speed and torque from Mini-HiL converts and sends them back to the rest vehicle model.

Due to the performance of these two e-motors and their control units the basic rotation speed was set at 200 rpm and the set rotation speed was added on this basic rotation speed, the road resistance was also appropriately scaled down. All these data should be transferred under a real-time environment.

The rest vehicle model was built with the software IPG CarMaker. The vehicle models are capable of real-time performance and valid up to the limits of driving dynamics. In this application one existing model was chosen as the rest vehicle model.

Obviously the validation environment of vehicles consists of track and traffic. In this application the track was built with the software IPG Road. In order to focus on the validation of the new validation concept the traffic was not be considered firstly.

As mentioned above the driver has been presented in two forms. The first form is a Matlab/Simulink model, which is able to set accelerator position and brake pedal position in real-time according to the maneuver and the difference between target velocity and actual velocity. The second form is a real driver on the driving simulator. This driving simulator provides a fully functional driver-side interior of the vehicle with all human-machine-interfaces and can be coupled with virtual environment, virtual vehicle model as well as physical vehicle on the test bench (Albers et al. 2009).

The hard- and software architecture is illustrated in the following Fig. 4.

3 Results

Some results of this application will be shown in this chapter. With these results the applicability of the new validation concept can be proved.

3.1 Driver Model

Figure 5 shows the set and actual rotation speed of the drive motor on the Mini-HiL test bench (place 1). As shown the simulated vehicle velocity according to NEDC (New European Drive Cycle) was transferred and converted from velocity to rotation speed as the set rotation speed and the drive motor could generally follow the set rotation speed.

The results (from 500 to 590 s) on CarMaker (place 2) are shown in Fig. 6, respectively the simulated velocity from the vehicle model. At the same time also the received set and actual velocity from the Mini-HiL is depicted (converted from rotation speed to velocity in meter per second) in order to compare the signals of both sides.

As in Fig. 6 diagramed, the converted set and actual velocity follow the simulated velocity very closely. It means that the simulated velocity could be fully and in-time

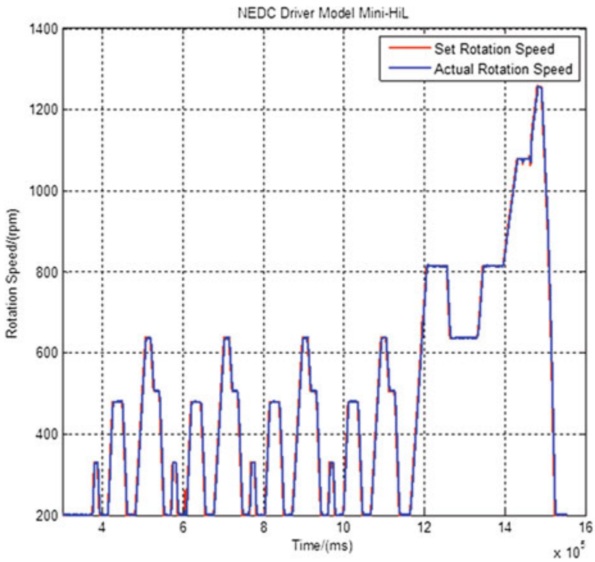

Fig. 5 Set and actual rotation speed of the drive motor

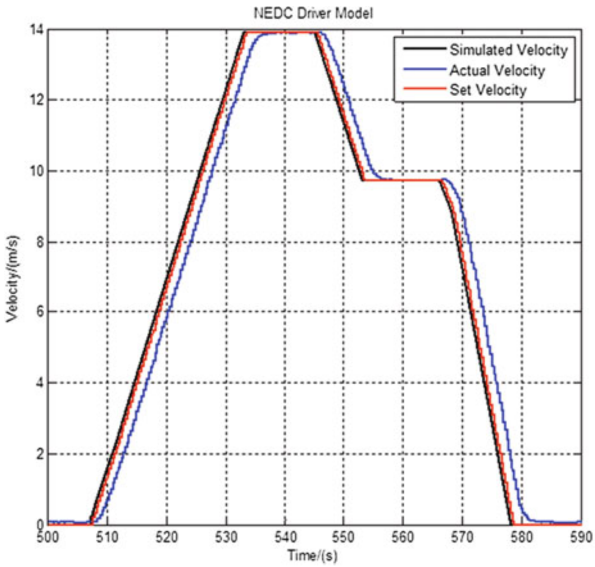

Fig. 6 Simulated velocity with results from Mini-HiL

transferred and implemented from place 2 to place 1. At the same time the actual rotation speed could also be fully and in-time collected at place 1 and transferred back to the Host PC at place 2.

The following Fig. 7 diagrams signals from 543 to 550 s. It shows that the transfer delay was about 0.4 s and the drive motor took about 1.5 s to reach the set rotation speed which is only affected by the adjustment control of the drive motor. As shown in Fig. 6 the delay affected the joint validation only hardly.

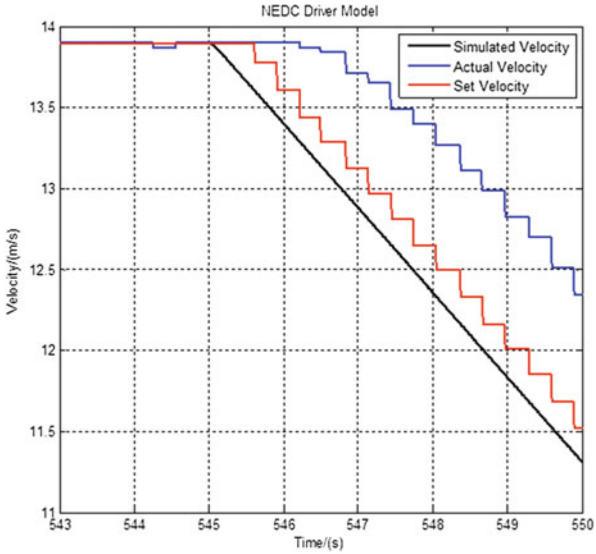

Fig. 7 Delay of the data transfer

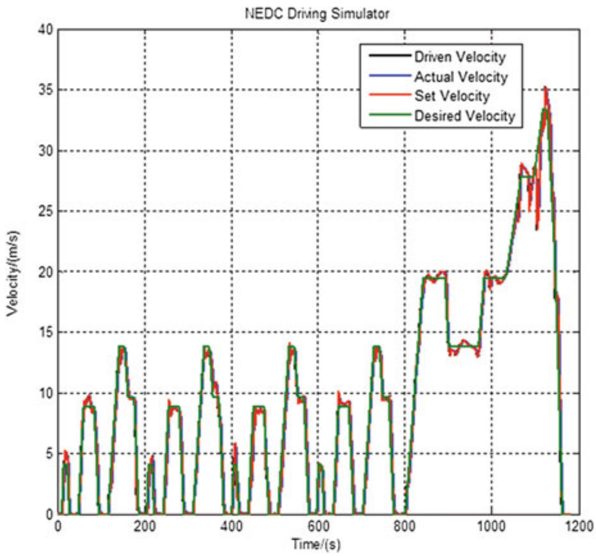

Fig. 8 Results with implementation of driving simulator

3.2 Driving Simulator

In order to verify the applicability of using the new validation concept to collect the market specific influences, e.g. driver behavior, the driving simulator was implemented in this application.

As shown in Fig. 8, compared with the simulated velocity from the driver model the driven velocity, which was caused by the driver on the driving simulator

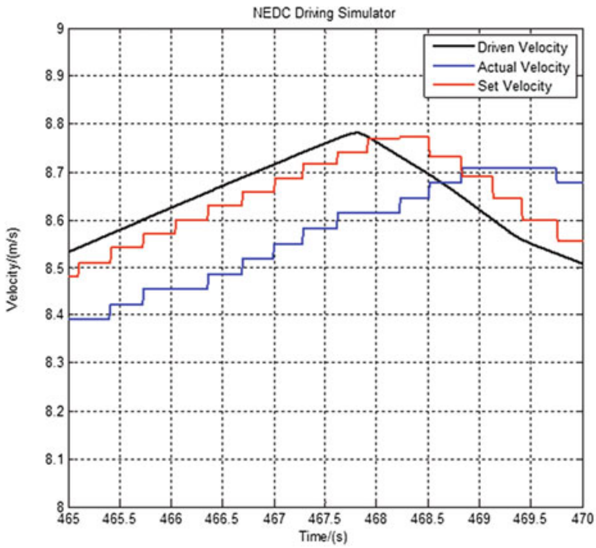

Fig. 9 Delay by implementation of driving simulator

and calculated by the vehicle model, is more dynamic and unpredictable. This is definitely a challenge for the joint validation.

The black line represents the driven velocity, however it is hardly to see. It means that the received set velocity from Mini-HiL followed the driven velocity very closely as well as by using the driver model, although the signals are more dynamically.

In order to realize the closed loop validation the driver saw the green line (NEDC) as desired velocity and the red line (received set velocity) as reference velocity during the first and third ECE R15 cycle (Urban Driving Cycle). Compared to that during the second and fourth ECE drive cycle as well as the EUDC (Extra Urban Driving Cycle) the driver was provided with the green line and the black line (calculated velocity from IPG CarMaker). As diagrammed in Fig. 8 there are no essential differences between these two driving modes. This proves the applicability of the new validation concept.

Due to the signals from 465 to 470 s as shown in the following Fig. 9, the delay was almost the same as by using the driver model and it affected the joint validation also only rarely.

4 Discussion

As mentioned in the chapter above, the applicability of the new validation concept was proved by the application example. The observed transfer delay between the two different sub-systems at different locations was about 0.4 s. In which way the validation result is affected by a certain delay, which of course depends on the quality of internet connection and also the performance of the gate notebook, has to be investigated in further research work. In the next step the concept of connecting different elements of the XiL-Framework will be scaled up to the dimensions of automotive use and validated in an intercontinental application between Germany and China.

5 Conclusion

In this article a new validation concept based on the IPEK XiL-Framework was introduced and proved with an application example. This new validation concept saves time and cost of cooperation between globally distributed departments and appropriately facilitates the multidisciplinary product development, which requires naturally very much cooperation between departments from different disciplines. With this new validation concept the location dependent characters of each target market can be considered in the early phase of development efficiently.

The main restriction of this new validation concept is the data transfer quality. With the rapid development of information technology, the X-in-the-distance loop concept would be more and widely applicable. In the further research work, ways to handle the delay have to be developed, since the data transfer is always attended to a certain time lag. It has to be researched, which transfer delay is admissible for a certain validation setup and possibilities to minimize the delay have to be investigated.

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