A Methodology for Interactive Spatial Visualization of Automotive Function Architectures for Development and Maintenance

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Abstract. In this paper, the authors utilize spatial visualization of automotive function architectures to enable novel, improved methodologies and workflows for the development, validation and service of vehicle functions. The authors build upon a prior approach for consistent data integration of automotive function architectures with CAD models. They show the benefits of the proposed novel methodologies by applying them to the scenario of developing an automotive signal light system. This demonstrates the capabilities of the new methodology in making a function-oriented development much more efficient as well as supporting testing and service.

1 Introduction

Today, the automotive industry has to face the challenges of an ever increasing complexity in development, validation and service. Two main causes can be found in an increasing diversity of variants and car configurations as well as in an increasing quantity of vehicle electronics and vehicle functions. Such functions like *Park Assist*, *Dynamic Light Assist,* or *Start-Stop Automatic,* are implemented as mechatronic systems, consisting of many different components like sensors, actuators and controllers. Moreover, many automotive functions involve a considerable amount of signals and information being communicated across multiple components and networks.

In automotive development today, function architecture diagrams are used for the design and validation of automotive functions and systems. However, such diagrams do not provide any information on the spatial location and distribution of function-related components and wires within actual vehicle configurations. Especially in modern, highly networked vehicles, it is rather difficult for developing engineers, function testers and service technicians to associate function-related facts, requirements and issues to particular components and wires in actual vehicle assemblies. Moreover, a mechatronic system implementing a vehicle function can be considerably different across particular variants and configurations, even in same vehicle models.

In our work, we address the above issue by proposing and investigating a novel methodology enabling an interactive, spatial visualization of automotive function architectures. We build upon prior work in which we have proposed an approach for consistent data integration of automotive function architectures with CAD models. In this paper, we apply this approach to an automotive turn signal light (TSL) system in order to explore that our interactive visualization can be of assistance in the early, function-oriented development as well as in the service sector.

2 Related Work

In the automotive industry, the increasing complexity and quantity of automotive systems, networks and related in-car communications present considerable challenges to many related domains like development, testing, and maintenance. Recent approaches show that one promising approach in mastering those challenges is to focus on methods of visualization to enhance quality and transparency of complex product data in related processes.

In the manufacturing industries, a typical and established application of virtual prototyping is a digital mock-up (DMU), which facilitates the utilization of CAD models for geometric investigations, such as assembly analysis or collision detection. For example, [12] show how challenges of heterogeneous, collaborative CAD assembly can be handled by DMU approaches. Moreover, approaches like [4], [7] and [8] focus on streamlining interfaces between CAD data and immersive virtual reality environments to enable high-quality rendering and improve immersive design reviews. However, such approaches focus on geometric analyses and do not incorporate function-oriented data.

A functional (digital) mock-up (FMU/FDMU) enhances traditional DMU by integrating numerical simulation models, like those created with MATLAB/SIMULINK, with CAD data to enable visual, functional simulation of product properties [3], [5]. For instance, an FMU framework has been proposed by [9] which helps to shorten development times of multi-domain systems and which allows integration tests at early stages of development. [6] use a wireless, real-time transmission to transfer simulation data to a rich 3D environment creating a comprehensible visualization of such data. Thus, their work assists in validation and presentation of simulation data, especially for non-exports.

In support of mastering the challenges of complex automotive systems, [11] provide a dual-view visualization for exploring functional dependency chains of in-car communication processes. One view focuses on hardware component dependencies using a space filling approach while the second view uses an interactive sequence chart to displays functional correlations. In addition, [10] have proposed a visual tool for exploring and communicating an automotive bus technology to support automotive engineers in the development of car communication networks. As a result, they found beneficial application in utilizing new methods for information visualization in a complex domain, in which the only access to data was textual so far. In addition, [13] developed a system for visualizing spatial sensor data to assist in the development of automotive driver-assistance systems based on environmental perception.

Summarizing, recent related work indicates the potentials of novel approaches of data and information visualization to assist in virtual prototyping. In many cases, such approaches are based on cross-system solutions and interdisciplinary interfaces. However, there is still a lack in tracing generic function architectures in actual vehicle assemblies and configurations to assist developing engineers and service technicians.

Therefore, our approach contributes in these fields by utilizing a synthesis of automotive function architectures with CAD/DMU data, exploiting synergy potentials in order to enable a new methodology for spatial visualization and analysis of function-oriented data.

3 Consistent Data Integration of Automotive Function Architectures with CAD Models

A promising solution to the recent challenges of automotive complexity is the relatively new *function-oriented* development approach that addresses the interdisciplinary development of vehicle functions and which helps to handle the high complexity in automotive development. At this stage, however, a function-oriented development does not fully exploit the capabilities of *virtual technologies*, which are fairly well-established, computer-based methods for the processing of virtual product prototypes. For example, function architectures are not yet consistently integrated with CAD models. Therefore, in prior work, we have proposed an approach for consistent data integration of automotive function architectures with CAD models (see Fig. 1) to exploit potentials of virtual technologies for a function-oriented development and to enable new, beneficial methods for a spatial visualization and utilization of such data [2]. This approach provides a system-independent XML description of function architectures to enable an integration of such function-oriented data with CAD models. For the CAD data, we exploit the PLM XML data format because it enables an integration of custom metadata with CAD data in established DMU and visualization systems. In this paper, we investigate how the novel methods that are enabled by this data integration approach can be beneficially applied in the fields of function-oriented development and service. All screenshots of the visualized data (Fig. 3-7) are captured with our prototypical implementation.

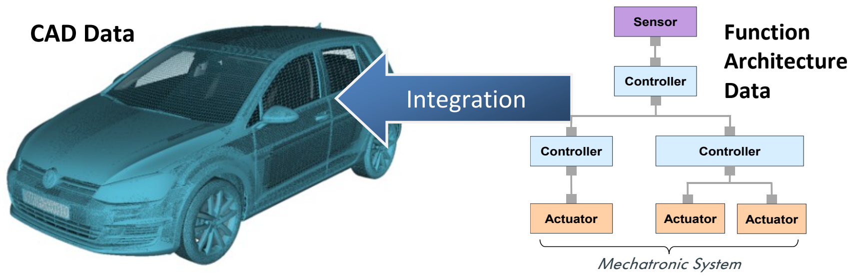

Fig. 1. We build upon our prior approach [2] of consistent data integration of function architectures with CAD models to create synergies and to enable new beneficial methods for an interactive spatial visualization and utilization of function-oriented data

Novel methods enabled by the proposed integration approach include:

- Highlighting of components and connections related to particular vehicle functions.

▪ Highlighting of components and connections considering specific attributes, values and other metadata related to vehicle functions.
▪ Acquisition of related function-oriented information for a given geometric part.

4 The Direction Indicator Function

In this paper, we focus on an automotive *left direction indicator* function to provide a representative and understandable use case that involves classic, discrete wires as well as network-based connections. This function is part of a turn signal light system, which is also used for different other tasks, including but not limited to indication of emergency situations, anti-theft alarm and the central-locking system. The proposed example of the direction indicator is a comparatively simple function, yet providing many beneficial use cases for our methodology. Fig. 2 illustrates a slightly simplified version of a corresponding function architecture diagram.

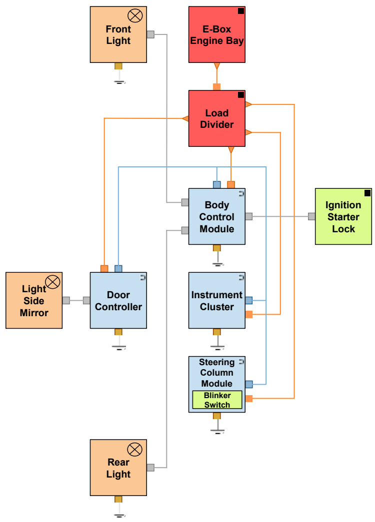

Fig. 2. The function architecture diagram of an automotive, left direction indicator function. In our approach, we aim for enabling a spatial visualization of such function architectures in actual CAD-based vehicle configurations

The above diagram shows an architecture involving different types of components and connections, including *controllers* (blue), *sensors* (green), *actuators* (orange) and *power supply units* (red). The function is triggered by a blinker switch attached to the steering column module (SCM) and the signal is communicated over a CAN bus to other controllers forwarding the signal to the particular light bulbs and control lamps in the instrument cluster. All related controllers need to be supplied with electric energy and, as well as most actuators, need a direct grounding connection for return of the electric current.

Function architecture diagrams are used in many stages of the automotive product life cycle, like in the development, validation and maintenance of vehicle functions. However, such diagrams do not provide information on the spatial distribution of function components and wires in actual car assemblies respectively in particular configurations. To fill this gap, based on our approach of consistent data integration, we have implemented an interactive, function-oriented visualization of the left direction indicator function in an established DMU visualization system. In Fig. 3, we visualized the complete electrical system in light blue, while all wires and components related to the direction indicator function are highlighted in dark blue. In the following section, we explore the benefits of the derived methodology for a function-oriented development and service.

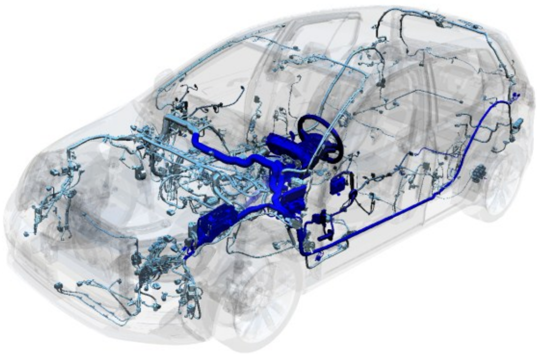

Fig. 3. A spatial visualization highlighting all function-related wires of the direction indicator function in a prototypical vehicle configuration

In modern cars, the amount of different vehicle functions can easily exceed a hundred different functions, involving many areas like safety, drivers' assistance, comfort, entertainment, etc. For example, Volkswagen differentiates more than thirty functions just for lighting applications, ranging from *Instrument Lighting, Parking Light* and *Headlamp Flasher* to *Dynamic Light Assist*. While most of these functions are described with architecture diagrams in a generic, vehicle-independent way, the actual implementation of a vehicle function can be different, not only across different vehicle models, but even across particular derivatives and configurations of the same vehicle model, resulting in a considerable complexity for both, development and service. The chosen example of the left direction indicator function involves a relatively clear and comprehensible architectural arrangement. However, many functions are of significantly higher complexity so that there is an increasing need for novel methodologies to enable mastery of this complexity.

5 A Novel Methodology for Automotive Function-oriented Development

Automotive developers and service technicians have to face the challenges of an increasing number of vehicle functions implemented in complex, distributed networks.

In support of mastering these challenges, in this section, we demonstrate that our visualization methodology can be of beneficial assistance, complementing usual architecture diagrams and increases transparency and quality in the development and testing of automotive functions.

5.1 Applications of our Methodology in Testing, Maintenance and Service

In both, the development and validation of vehicle functions, as well as in repair and maintenance jobs, it is a common task to trace error causes based upon given failure symptoms. Such failures can be caused by line break (i.e. due to crash, fatigue, wear, etc.) and/or short-circuit (mass or 12V). In this use case, we assume an issue in the **power supply** to the *Steering Column Module* which is a generic cause of error with a relatively high probability. In most current cars, power supply units are critical components as they provide all systems with the necessary electrical energy. In particular, the electrical energy is created by a generator in the engine bay, temporally saved in the battery, and then distributed to the electronic components via energy dividers and/or fuse boxes.

This use case provides a fairly simple example of how our methods can assist testers and service technicians in the tracking of function-related wires. The architecture diagram in Fig. 4 provides information about the involved components and connections. Our visualization complements this diagram by providing information about the actual location and distribution of these components and connections in a real car configuration. The route of the power supply wire is clearly visible, starting from the generator/battery (E-Box) over the load divider to the steering column module, as it also could be approximately expected by the assembly locations of the involved components. In this example, the topology of the diagram is comparatively closely related to the actual assembly topology which is not necessarily true in practice.

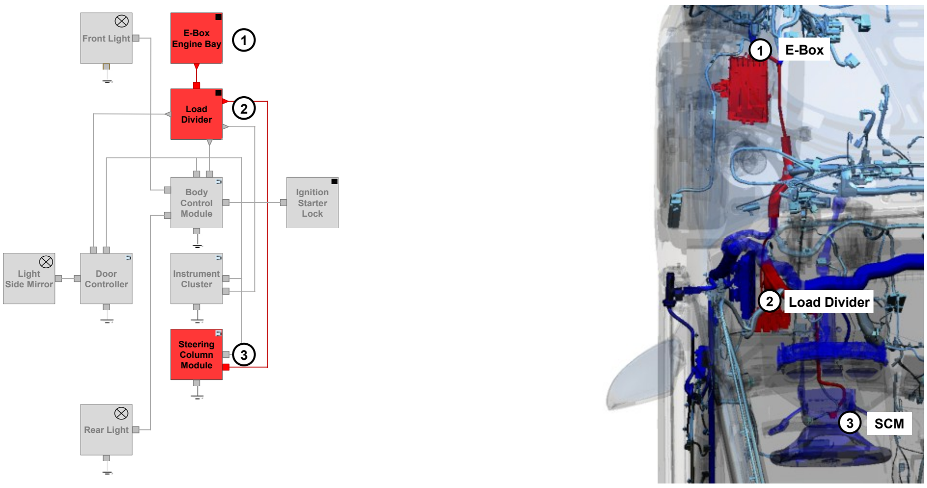

Fig. 4. On the left, all components related to the power supply of the steering column module are highlighted in the architecture diagram. On the right, we utilize a spatial visualization that highlights these components and wires in an actual car assembly

Another potential cause of error can be an issue with the **grounding connection** of the steering column module. Grounding wires connect function components to the vehicle chassis to enable a return of the electric current. This use case differs from the previous one in that it strongly makes the limits of function architecture diagrams apparent, because, in this case, the diagram does not provide any information on the distribution of the grounding connection at all (see Fig. 5). In addition, the location of grounding bolts can be very difficult to detect in practice because they can be hidden behind caps and carpets. Moreover, dependent on vehicle platforms and decisions and needs made by the chassis fabrication, the bolts can be located in different and unexpected positions.

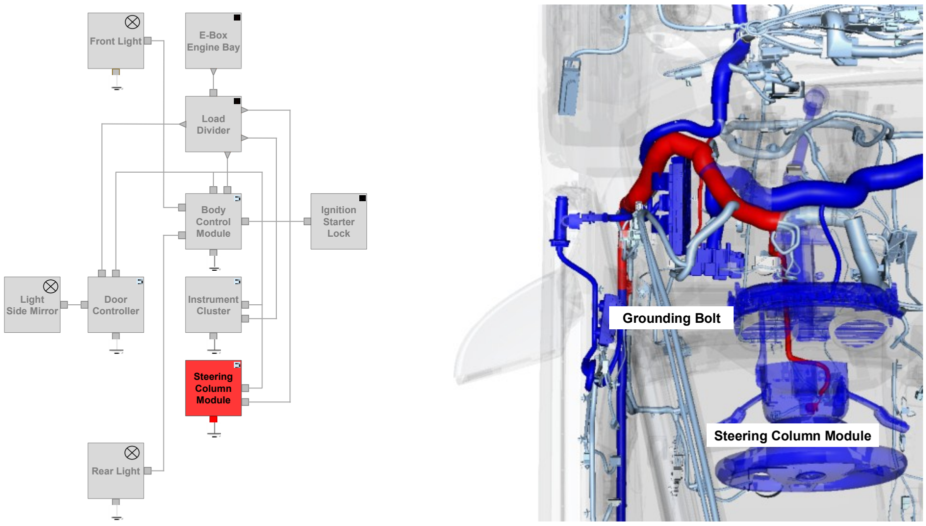

Fig. 5. Our visualization (right) provides information about the actual routing of the grounding connection which are not visible in the function architecture diagram (left).

In this example, our spatial visualization enables an efficient localization of the actual grounding connection and can beneficially assist function testers and service technicians to trace affected wires and related function-oriented information.

5.2 Applications of our Methodology in function-oriented Development

The **controller area network** (CAN) is a field bus that is used for the communication between automotive systems and function components. The CAN bus is widespread in distributed embedded systems due to its electrical robustness, low price, and deterministic access delay [1]. Automotive CAN busses are frequently implemented using a star topology which has some advantages in case of failure propagation regarding particular components. For instance, if there is a communication issue due to a software error in a particular component, the other components of the bus are still able to communicate properly. However, physical failure of a component may still influence all other members of a CAN bus. Therefore, a failure of a vehicle function can still be caused by a short circuit in a system component of the bus network that is not directly related to the function at all and thus is not necessarily expected at first sight. In this case, information about the location and distribution of the complete CAN network are necessary for further investigations. Therefore, we have extended the diagram to include all CAN members and created a corresponding visualization highlighting the full CAN network (see Fig. 6).

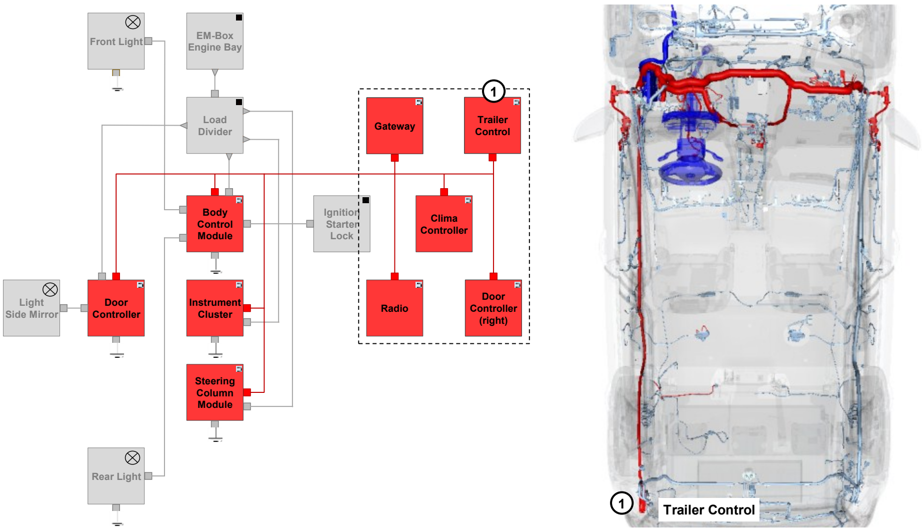

Fig. 6. We have enhanced the function architecture diagram (left) by adding all other controllers that are also connected to the involved CAN-bus network. The visualization (right) shows the complete CAN network distribution and enables statements on summed wire lengths.

While this use case can also be of benefit for service applications, at this point, we shift our focus to applications in development. An issue in a function-oriented development is that system designers of network architectures are usually not aware of the distribution of the designed networks in actual car configurations, at least not at early stages of development. Moreover, we recapture that the topology of architecture diagrams usually does not represent the actual topology of components in a car assembly because it is primarily designed after functional preferences and generically designed to be valid for many different vehicle derivatives. For example, the *Trailer Control* in the diagram in Fig. 6 is located in the upper right. As revealed by the visualization on the right, however, however, this controller is actually located in the left rear corner of the vehicle assembly.

Our visualization provides many benefits for the development of function architecture networks. For instance, it enables statements on the lengths of network wires and their distribution. In automotive development, for physical reasons, wire lengths in networks are limited to avoid errors in synchronicity due to long runtimes and uncontrolled communication caused by reflections and parallelism of signals. Our visualization enables developing engineers to incorporate information about the summed length and distribution into the architecture design so that potential errors can be identified and avoided at earlier steps of development. In terms of variants and configurations, an approved architecture that works well in a small car does not necessarily fit in a large vehicle since wire segments can exceed the limits. Therefore, our visualization helps in applying and validating existing architectures for different vehicle configurations and variants.

In addition, our visualization enables statements on potential risks due to information access about which areas of a car may affect particular functions on crash situations. For instance, keeping on the example of the left direction indicator function, Fig. 6 illustrates the full CAN network revealing wires routed to the left rear corner including the *Trailer Control* so that it becomes visible that a rear-end collision in a parking situation can cause a short circuit in the Trailer control and thus a failure of the left direction indicator function.

5.3 Interactive Function-oriented Data Exploration

Based upon our novel data integration approach, an engineer can now also use the geometric data or, rather, its visualization to select a particular geometric part in order to access related function-oriented architecture data. This way, he can easily obtain function-oriented information related to this geometric part, for example:

- **Functional relations**: To which function(s) does this geometric part belong to?
- **Type**: Is this geometric part a controller, sensor or actuator? Or, if it is a wire, is it a signal, grounding, etc., wire? Which other properties does it have?
- **Network relations:** If the part is a wire, is it involved in any CAN-networks or other buses?

These are just a few examples of questions that can be answered by the proposed methodology. Theoretically, any metadata that is available from the function architecture diagrams and other sources, and which has been input in the data integration, can be evaluated for specific applications. Therefore, such methods can be used as complements for digital mock-up, enhancing geometric CAD data with function-oriented information. Fig. 7 illustrates an example in which the *Body Control Module* is selected to obtain function-oriented information. A list of related functions is displayed and the *Headlamp Flasher* function is highlighted in the virtual prototype.

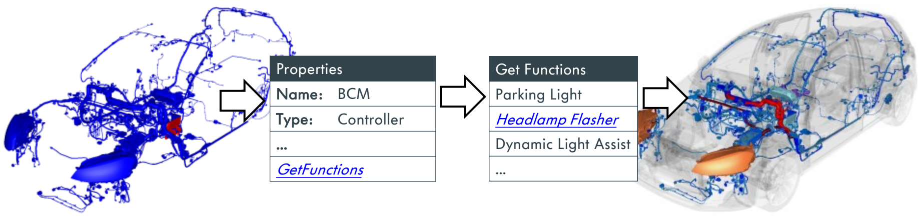

Fig. 7. Our methodology enables an interactive exploration of CAD data in order to obtain related, function-oriented information for selected geometric vehicle parts

Another use case would be in the service center. For example, a service technician might know that a particular component is defective. With our novel methodology, he can look up this component in the visualization, select it, and thus quickly obtain related function-oriented information. As a result, he gets to know which functions may be potentially malfunctioning due to the defect component.

Finally, since our methodology is implemented in an established visualization system that is already used for conventional DMU applications, a fair user experience is ensured since engineers are able to use a well-known tool. In addition, our methodology supports all usual operations that are available in regular DMU, including object manipulation like zoom, rotation and grouping. Moreover, different filters can be used to highlight particular geometric parts in respect to different areas of interest respectively depending on specific attribute values.

6 Conclusions

In this paper, we have explored beneficial applications of interactive, spatial visualization for the development, validation and service of vehicle functions. Our methodology enables function testers and service technicians to easily locate and trace function-related components and connections in actual vehicle assemblies. Moreover, it enables reclusions about functions that may be potentially malfunctioning because of their relationship to defect components. In addition, our methods enable statements on network lengths and distribution at early development stages. We have shown that a function-oriented visualization is able to significantly assist in development and service processes and provides an appropriate solution in mastering challenges of increasing automotive complexity.

Our approach provides much potential for future work. For instance, the proposed methods can be enhanced by automatized interfaces and further improvement of end-user tools to advance a holistic integration into daily work processes. Further work can be in extending visualization tools with advanced, function-oriented functions like the evaluation of network lengths and other application-based reporting functionalities. In addition, our methodology can be integrated in hand-held devices for augmented reality applications so that function testers and service technicians get access to function-related information based upon the currently viewed vehicle assembly part.

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