Title:

Time-efficient and Accurate Spatial Localization of Automotive Function Architectures with Function-oriented 3D Visualization

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Introduction:

Today, the ever-increasing complexity of modern cars is one of the primary challenges in the automotive industry [3],[6]. One significant complexity driver is the high amount of vehicle electronics respectively vehicle functions, like Park Assist, Dynamic Light Assist or Start-Stop Automatic. Such functions are implemented as complex, distributed mechatronic systems, consisting of sensors, actuators and controllers. A function-oriented approach to development addresses the interdisciplinary implementation of such systems. This approach complements a component-driven development by extending the overall focus on functions rather than single components and it is a fundamental requirement to handle the increasing complexity in automotive development [3],[5],[7].

Virtual technologies are interactive, 3D (preferable immersive) computer-based methods for the processing of virtual product prototypes and provide an important tool in the automotive product lifecycle management (PLM) [4],[8]. A typical field of application is a digital mock-up (DMU), which describes a virtual product model, usually a 3D model based on CAD data, that is used within different areas of the PLM, like design, validation and simulation.

In our previous work, we have proposed an approach for consistent data integration of automotive function architectures with CAD models to exploit synergies and to develop novel, improved methodologies and workflows for the development, validation and service of vehicle functions [1],[2]. The term *function architecture* defines, by our definition, a methodology that allows to identify all components that make up a specific function of the vehicle including the connections between these components. So, a function architecture should provide a means to identify all components and electrical connections in the vehicle necessary to implement, for instance, the wipers (a simple example) or the Park Assist (a rather complex example).

In the following, we first present one of the major challenges with function-oriented automotive design (identifying quickly the geometric distribution of a function's components and connections), present a solution, and, finally, we evaluate our function-oriented methodology concerning the task of time-efficient and accurate spatial localization and cognition of automotive function architectures in particular vehicle projects.

Main Idea:

The time-efficient and accurate spatial localization of the distribution of components and wiring harness of a specific vehicle's function in the design of new car models is an important task throughout the automotive development process. We define this task as *Geometric Function Localization Task* (GFLT).

The GFLT can be crucial in many use cases. For example, such use cases include the design of inter-vehicle networks, evaluation of critical function aspects, identification of synergy and savings potentials, enabling statements on functional failures depending on crash zones, communication and mutual understanding of function architectures, and a function-oriented development in general. Moreover, a time-efficient solution for that task is particularly important given that the locations and the distribution of components and wiring harness of a particular function do not only differ between vehicle projects, but also between variants, configurations, and derivatives within the same vehicle projects.

In current automotive development practice, the GFLT is very cumbersome. One possible way for obtaining kind of information on spatial locations of function components is to contact each person who is responsible for a specific function or function component. But this way is very time-consuming and prone to errors, considering that information have to be gathered across multiple different domains/departments for a significant amount of function components (like ten, twenty or even more), while at the same time, there are usually frequent changes in the vehicle projects, variants and designs. Retrieval of information about the wiring harness between all function-related components requires significant manual effort, e.g. by using wiring harness diagrams (see Fig. 1). Moreover, wiring harness diagrams do not provide any information on the exact spatial location of these wires in a particular vehicle project. While spatial information of vehicle parts are available due to the CAD data and digital mock-ups, such data does not include any function-oriented information so it is highly time-consuming and prone to errors to manually identify the parts that are related to particular vehicle functions in this kind of data.

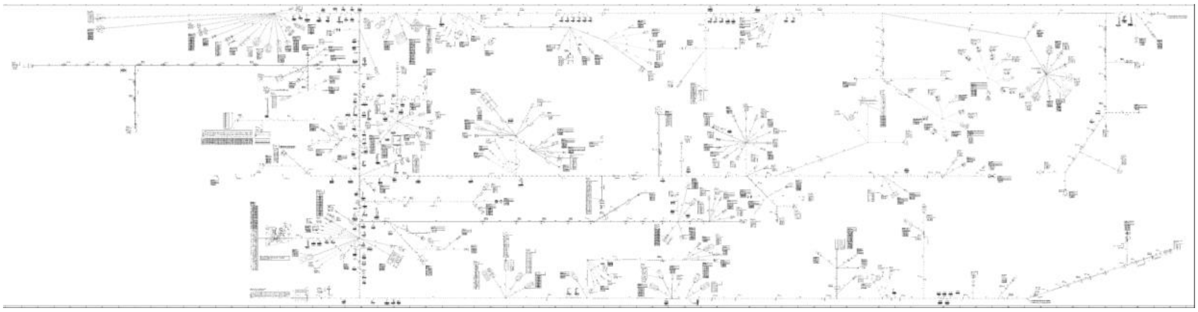

Fig. 1: Section of a hypothetical automotive wiring harness diagram; identification of function-related components and connections is a cumbersome process using this type of data.

In this work, we propose interactive 3D tools to solve the GFLT, based on our function-oriented visualization methodology [1],[2]. In addition, we show that these tools are capable of successfully performing this task in a time-efficient and accurate way. To do so, we present a case study which compares our method to a usual method based on classic wiring harness diagrams to assess task-completion time and task-correctness. In addition, we propose a 3D-grid approach using geometric clusters to verify that our visualization methodology enables accurate and precise recognition of the spatial distribution of function architectures in vehicle projects.

Part I: A User Study on Task-Performance

A function-oriented development requires a highly interdisciplinary collaboration between many different domains and departments of automotive development such as architecture design, wiring harness development and virtual prototyping. Successful performance of the GFLT is crucial for those heterogeneous domains and a high diversity of use cases. Thus, the target audience of the GFLT is supposed to be a generic range of users without any particular expert knowledge in one specific domain. Therefore, all subjects in our user study have been students with technical background but without expert knowledge in a particular field of automotive development. Moreover, this subjects selection ensures that the study results are not possibly distorted due to knowledge mismatch and it excludes that some of the subjects are able to solve the GFLT due to specific knowledge advantages without using the actually assessed methods.

The subjects were split into two groups (A, B). Group A had to complete the given task with the conventional, currently available method using wiring harness diagrams, while group B used our novel function-oriented 3D visualization method (Fig. 3). The task involved the correct identification of the electrical connections between a given set of function components for a specific vehicle function. All subjects had to solve the task for three different, hypothetical vehicle functions. Both groups started with a list of all components related to the respective functions. The steps of the task with both methods included identification of the function components in the provided data, identification of the function-relevant electrical connections between the components, and proper transfer of this information to a special template (see Fig. 2). The subjects had to draw in the correct wire routings into the template, so we could measure task-completion time and correctness of the results.

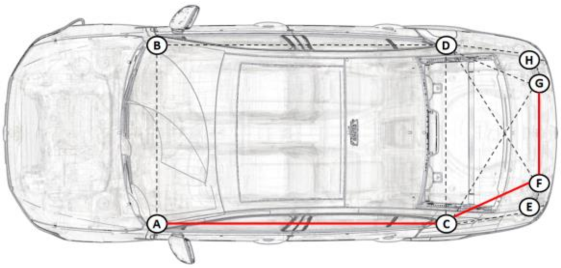

Fig. 2: Our GFLT task solution template properly filled for a specific function architecture.

The template simplifies the task in two ways: It shows a top-down view including X and Y dimension but not Z, and positions of function components (A to H) and valid routings are predefined. Leaving out the Z dimension enables comparison between our novel method and the conventional wiring harness method because the latter is not able to provide the Z information at all. In addition, we found that the top-down view is already sufficient for many use cases. Even with the given simplification measures, we demonstrate that our method provides a significant benefit for successfully performing the GFLT. In addition, in the second part of this work, we will investigate accurate GFLT performance based on use cases where a full spatial recognition is relevant, overcoming the gaps of the conventional methods.

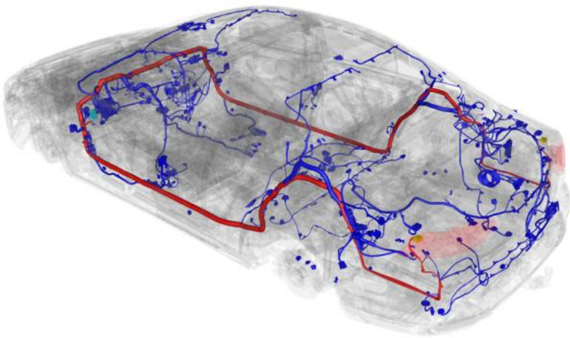

Fig. 3: A function-oriented 3D visualization created with our methodology which highlights function-relevant wires (red) and shows their distribution in the vehicle.

The results of our case study indicate that our function-oriented 3D visualization methodology provides a significant benefit in terms of time-efficiency to successfully perform the task. In addition, we found that this method is also less prone to errors in comparison to just using wiring harness diagrams and conventional CAD data. The detailed results are included in the full paper.

Part II: Utilizing a 3D Cluster Approach in Support of the Function-Oriented Visualization Method

A rough recognition of the spatial distribution of function architectures is sufficient for many use cases. Nevertheless, there are still a considerable number of use cases that benefit from a highest as possible accuracy in terms of the GFLT. These use cases are typically based on dividing the vehicle into different geometric areas. For example, there are areas in a vehicle with statistically high probabilities of being affected in crash situations. Other examples for area-based approaches include different temperature zones, vibration stress areas, mechanical shock areas and areas prone to dust and splash water.

Considering use cases like in the above-mentioned examples, we extend our task scope in a way that it requires full spatial recognition of the function architecture distribution, including X, Y and Z dimension. In order to measure the capability of our method to fulfill this extended task, we propose a 3D-grid approach using geometric clusters (see Fig. 4). Thus, the vehicle geometry is cut into a number of N cubic clusters. This approach is based on detecting the clusters that are touched by the particular function architecture elements. This approach is scalable, while a higher number of clusters (more, smaller clusters instead of fewer, bigger ones) corresponds with a higher granularity in assessing the spatial accuracy of the evaluated method.

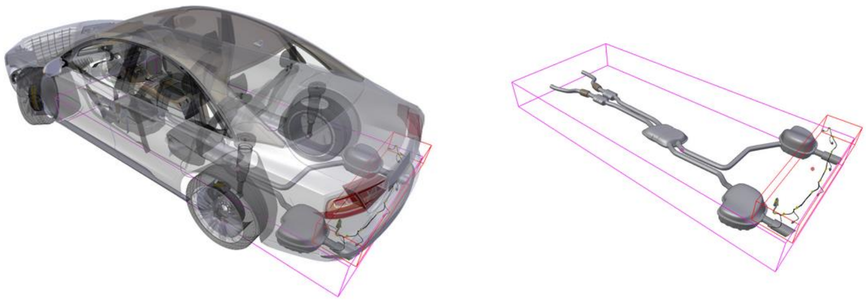

Fig. 4: An example of the cluster approach, involving two geometric clusters in the illustrated vehicle.

To verify the accuracy of our function-oriented 3D visualization method, we have conducted a case study to show that our method is capable of providing highly precise statements on the spatial function architecture distribution. Therefore, we use the 3D grid approach to create a cluster grid, dividing the full vehicle geometry into a fixed set of equal-sized clusters. We have used two different sets of clusters for being able to investigate low and high granularities. We set up questionnaires which included checkboxes for all clusters. For each checkbox, the subjects had to check if the respective cluster is touched by the considered function architecture or not. All of the subjects had to use our 3D visualization methodology to retrieve the necessary information. For analysis of the function-oriented 3D data, they could use typical functions like zoom, rotation and highlighting in the 3D tool to explore the data.

The results of this work indicate that our method provides high accuracy in retrieving the spatial information required by the GFLT. Moreover, as it concerns practical application in daily use cases, the cluster approach should ultimately be automated and implemented as a feature within a 3D visualization tool, providing hundred percent accurate statements at nearly instant speed. In addition, the choice and properties of clusters can be adapted to fit specific use cases and the approach can be used similarly like visual programming languages. By following this approach, a possible feature can be an automatic report on the percentage distribution of a vehicle function's concrete implemention within the complete vehicle. Moreover, clusters can be classified by the end users, for example, by defining their crash criticality. With this exemplary classification, a possible feature for a respective tool can be a report on the percentage of the function architecture that is located in critical areas.

Conclusions:

The results of our research indicate that our function-oriented 3D visualization methodology provides an efficient solution to identify and recognize the accurate spatial distribution of function architectures in specific vehicle projects. In comparison of using methods that include just usual CAD data and wiring harness diagrams, our method overcomes limitations of such data in terms of informational content and it is more time-efficient and less prone to errors. The method is easily applicable for non-experts and thus can be used across multiple domains of automotive development. Moreover, the clustering approach enables novel, valuable features for function-oriented 3D visualization tools. In summary, our method is able to streamline the performance of function-oriented tasks requiring quick and correct recognition and localization of spatial information of vehicle function architectures. It supports automotive engineers in mastering the challenges of current, highly-interdisciplinary function-oriented development and the ever increasing complexity in automotive development. Our research also leaves potential fields of future work, like research on function-oriented interaction metaphors and usability studies of respective tools.

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