35th International Electric Vehicle Symposium and Exhibition (EVS35)
Oslo, Norway, June 11-15, 2022

Concept of a service-oriented vehicle energy management and evaluation of the data quality of related services

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Summary

The complexity of vehicle energy management has increased steadily in recent years. This is due to stricter emission regulations, new drive technologies and the increasing number of electric consumers. The ongoing change in E/E architecture, rising requirements for flexibility and upgradeability as well as automated driving functions will further increase this issue. A service-oriented software structure can help to manage this complexity. Therefore existing concepts for vehicle energy management must be adapted and expanded to achieve the desired flexibility and reduction in complexity.

Keywords: communication, EV (electric vehicle), power management

1 Introduction

For a long time, vehicle E/E architectures were function-oriented. This was due to a relatively low level of complexity. The functions of vehicles were developed separately and coordinated later in the development process. This was possible because a function was executed by a single electronic control unit (ECU). The development effort for individual functions is therefore relatively low and they can be developed independently of each other. However, the integration of the functions into the overall system and their coordination among themselves is a time-intensive problem with a high degree of complexity. In addition to the number of functions in vehicles, the quantity of ECUs has also risen sharply. This causes restrictions in terms of weight, installation space, and package optimization of the overall vehicle. It can be assumed that this trend will continue and that the number of functions in the car will rise. In addition, the complexity in vehicle development will increase further. In order to control the complexity, centralization is being pursued. Currently, centralization is taking place at the domain level, which is characterized by domain-specific powerful ECUs. The ECUs arranged under it have a domain-specific E/E functional scope. Further centralization will lead to an architecture with a supercomputer and some domain-independent ECUs. The vehicle components are designed to fulfill a set of specific functions and are connected by their precisely specified interfaces. Another aspect of this functional architecture is the dependency on the hardware. Whenever a new function is integrated into the model or the hardware is changed, the design of the functions and the coordination of the interfaces must be redone. The required additional effort makes it unreasonable to upgrade or extend vehicles as the product life cycle of vehicles is decreasing in the last few years. Furthermore, it is necessary to adapt the existing or design new functions when a new variant or model of a vehicle is developed. [1], [2]

Present energy management (EM) systems do not offer the optimal structure for service-oriented architecture (SOA). They mostly use characteristic diagrams or rule-based procedures as well as a static prioritization of the consumers [3].

1.1 Trend of service-oriented architecture in the automotive industry

SOA is a paradigm for designing software architectures that enables greater flexibility and modularity. This is accomplished by encapsulation of data with high dependence and loose coupling between the different services. The interfaces have thus high importance since these must be completely abstracted from the implementation of the service. Similarly, a uniform specification is required for the entire system. [4]

As an example, imagine the design of a battery system. It offers the request *vehicle status* and the guarantee *energy storage information*. Vehicle information include all information from the vehicle that are necessary to control the energy storage e.g. whether the vehicle is in standby, charging or driving mode and the safety status. Whenever we exchange the battery with another energy storage e.g. a supercap or a different battery, the services on the vehicle and the energy storage system (ESS) can stay the same. The supercap might have other internal functions to control its behavior and different limits. As an example the battery could have several temperature and voltage limits and the supercap has only one temperature and current limit. As long as the guarantee contains the information for *limit reached* regardless of which physical limit has been reached (temperature or current), *maximum output power* and the *pause time* there is no need to change the service on the vehicle side. Another upgrade scenario concerns the driver assistance functions as described in [5]. Figure 1 a) presents the battery communication of state-of-the-art vehicles. This architecture has a battery management system (BMS) which is connected via CAN to all other ECUs of the vehicle. In the project UNICARagil, several vehicles were built to combine innovative and disruptive concepts. To enable a highly safe and reliable electric propulsion system, the E/E-architecture consists of four zones (front right, front left, rear right, rear left). The main idea is to have redundant hardware in case the energy storage or other parts of the electric supply systems fail. Furthermore, it

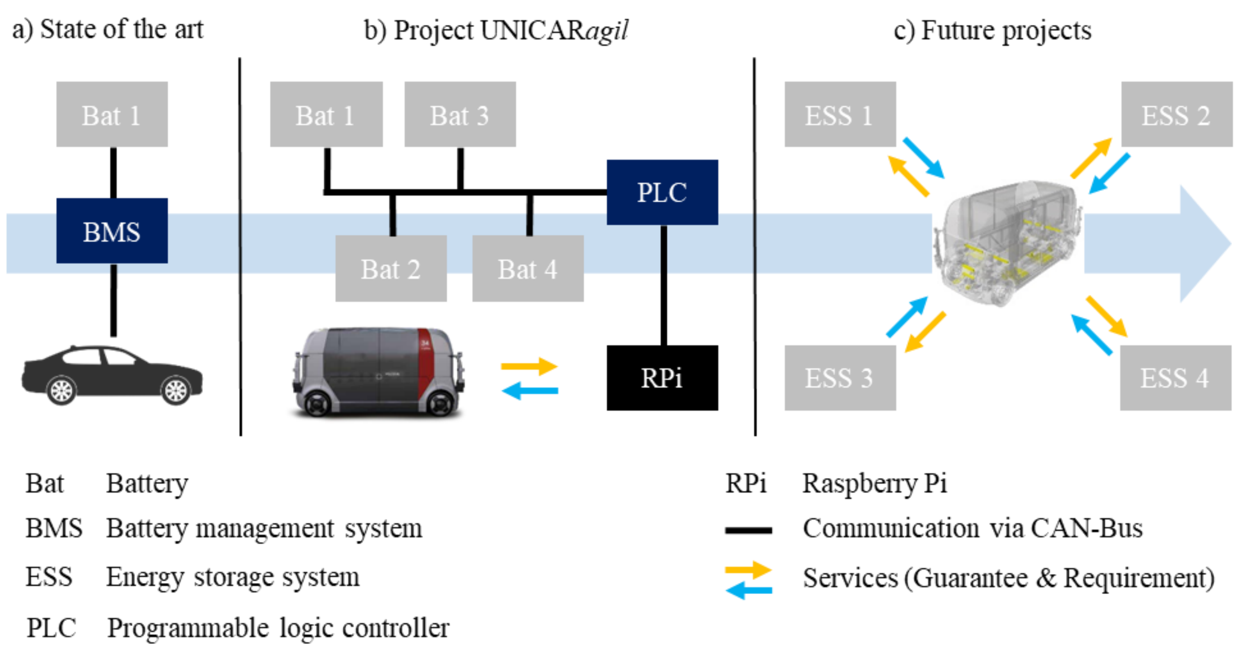

Figure 1: Transition to a modular architecture for the energy storage system supported by SOA according to [5]

is possible to isolate a single zone. This function is necessary in case there is a fault caused by one of the consumers' e.g. short circuit. After the faulty zone is separated, the remaining powernet can still operate with reduced performance. Figure 1 b) shows the batteries of the UNICARagil vehicles and their communication with the vehicle in a schematic diagram. The batteries communicate with a control unit and a gateway via CAN-Bus. A separate microcontroller transforms the CAN messages into services. With this implementation, the BMS interacts with the other systems. In the later discussed automotive service-oriented architecture (ASOA) the consuming services are called requirements and the producing ones guarantees. [7]

This approach can be extended by splitting the services, so each energy storage works independently as indicated by Figure 1 c).

2 A service-oriented energy management for electric vehicles

The vehicles, which were designed in the project UNICAR*agil*, aim for autonomous driving according to SAE level 4. Figure 2 shows a simplified principal scheme of the automation. The main aspect is that a regular and a safe-stop trajectory are planned based on the vehicle environment model. The self-monitoring checks the state of the critical systems in the vehicle and provides this information to the behaviour and trajectory planning. One crucial aspect is the EM as it provides all necessary information about the energy status of the vehicle. Further inputs could be the thermal management, the driving modules, or active safety systems. Consider omitting some of the systems and instead of forwarding all information directly to the self-monitoring. This helps to reduce the number of systems but is contrary to the approach of the SOA to the encapsulation of data with high dependency.

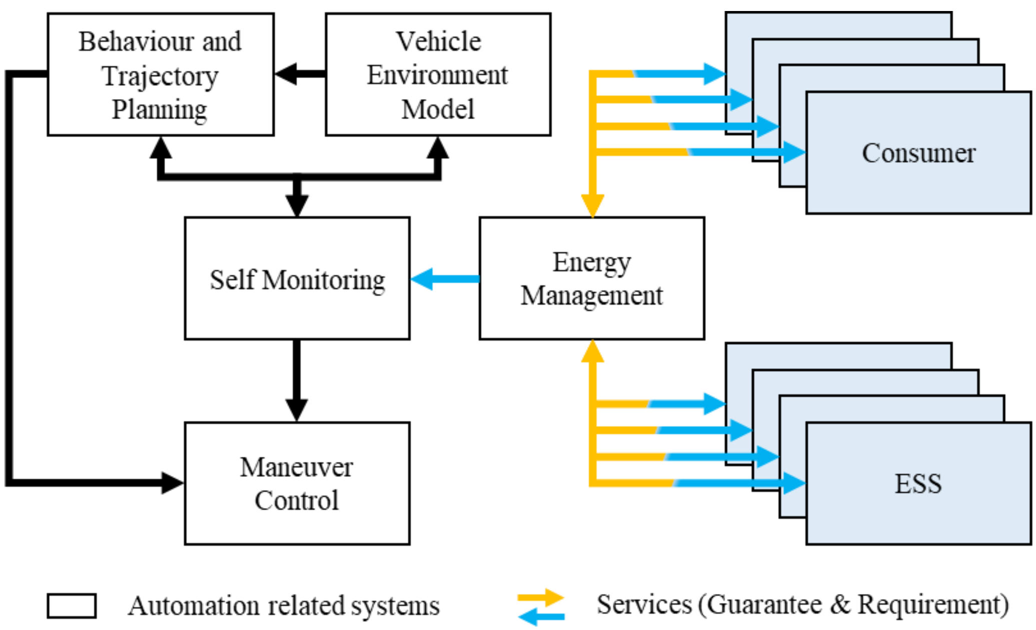

Figure 2: Extension of UNICARagil automation by an energy management according to [8]

2.1 Service Definition

The EM comprises the services for distributing power between the functions and providing information for controlling the vehicle. While it monitors the power distribution, the automation system controls the drive unit. To ensure that all the required services for the safe stop trajectory are supplied in any scenario, prioritization is necessary. Furthermore, the maximum energy for the safety stop trajectory must always be observed by the self-monitoring. Before the remaining energy reaches this critical value, a safe stop must be executed. Thus, the EM can be understood as an information source for vehicle automation and a control unit for all systems that are not necessary for the safe-stop and autonomous driving. This includes mainly the comfort systems. The main tasks of the EM are hence:

- Evaluate the energetic status of the vehicle
- Determine limits for non-safety and safety-relevant services
- Coordination of power for non-safety relevant services
- Provide information about the energetic status of the vehicle

In previous EM systems, it was the task of the energy management to track the remaining distance and adjust the power demand of the loads. As automation and self-monitoring determine vehicle trajectory and behavior, powertrain control and remaining range monitoring is handled by the self-monitoring.

Figure 3 presents an overview of the services that are necessary to fulfill these tasks. In [9] the ASOA is introduced, which defines the interfaces of the consuming services as requirements and the producing ones as guarantees. Besides the messages listed below, additional information is necessary to help with the conversion of services and to describe the data quality.

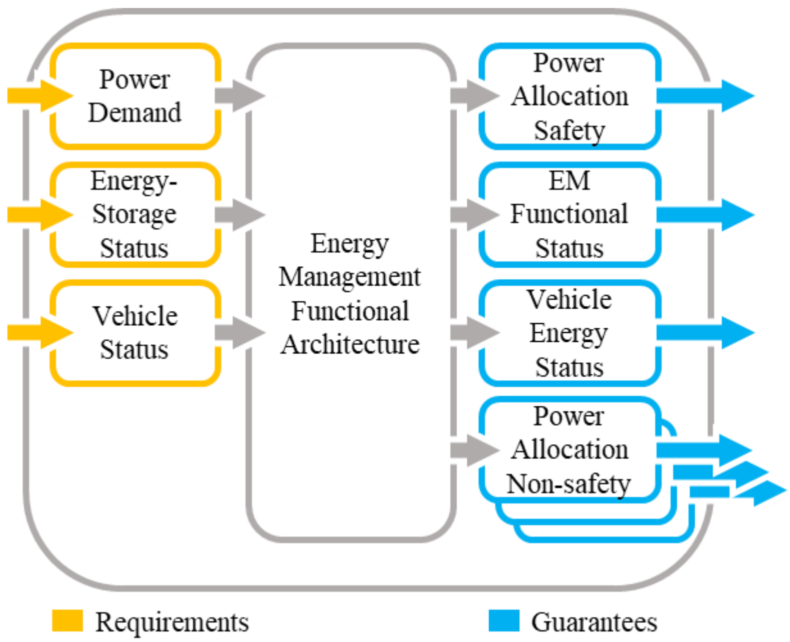

Figure 3: Requirements and guarantees for a service-oriented energy management service

The EM has three consuming services. The *power demand* requirement includes the messages for the desired power, the priority of the service concerning safety, a predicted time horizon of the demand, and the device name. The device name is necessary because the guarantees of all systems regarding their energy demand are linked to this requirement. Related to the time horizon e.g. an ECU responsible for instance the powertrain, will need the requested power immediately. Less important consumers or those that do not enable functions directly perceivable by the customer can generate a more flexible energy demand [10]. By this, the complexity in the EM is reduced as it only needs one guarantee for the power demands of all consuming systems.

The second requirement of the EM is the *energy storage status* requirement. As mentioned earlier, energy storage may change in the life cycle of a vehicle. This may concern the size, but a change in technology is also possible. To meet this, the requirement can be connected to all energy storage guarantees in the vehicle. The energy storage in an electrical vehicle is not necessarily a battery, so the messages must fulfill the demands of systems like flywheels, supercaps, or fuel cells too. As this EM is designed for autonomous electric vehicles, we assume, that all of these energy storages have an electrical output. The necessary messages, therefore, include the information about the electrical outputs (current, power, voltage), their status regarding safety (State of Function, temperature), and energy prediction (State of Charge (SOC), State of Health (SOH)).

The third requirement includes information about the vehicle's status, it is called *vehicle status*. This includes the messages with information about the type of operation (autonomous, manual, safety) and the availability of crucial functions. Details about the comfort systems are not necessary as the EM does not consider them when they send no energy demand message or the message is implausible.

On the one hand, there should be a maximum in flexibility and reusability but a safe operation is more important than ever, since the vehicle operates autonomously. To fulfill this demand, there is a separate guarantee designed for safety-related services and non-safety-related ones. Components and thus also services are exchanged and modified in the lifetime of the vehicle. This leads to an increasing amount of combinations and possible error sources. By separating the energy allocation into safety and a non-safety related service, it is possible to use different strategies for changes and updates e.g. the energy allocation for safety-related components is updated under a restricted environment as in a repair shop. Whereas the rearrangement during runtime is allowed when the vehicle is not driving. For the non-safety-related tasks, it is possible to do this while runtime and by over-the-air-update. Both energy allocation services include the messages of the allocated electrical power (voltage, current), the related time horizon, and the information to which device the information is related. The energy allocation for the non-safety-related services should operate with different priority levels to fulfill the passengers' needs most efficiently. Depending on the number of comfort systems, different variations of the energy allocation for non-safety-related systems are possible. One option is to use only one service, which makes it the easiest as all non-safety-related services have the same interface to the EM. The disadvantage of this variant is the big amount of unused messages. Another alternative is to split it up into several priority groups, which will reduce this problem but will increase the number of services.

For the overall vehicle management, remote operation, trajectory planning, and other systems to operate, the functional status of the EM as well as a general electrical status of the vehicle is provided via the services *EM functional status* and *Vehicle energy status*. The vehicle energy status includes messages about the power balance, remaining energy, remaining operation time in this status concerning safety and performance aspects such as battery temperature, SOC, and SOH. The *EM functional status* sends the results of the self-diagnosis of the EM as messages, e.g. if errors are currently present or have occurred in the past.

2.2 Metric for evaluating the quality of an architecture

When designing a service there are many degrees of freedom and dependencies on the overall system. This makes it hard to determine their quality and suitability. The most common way to do this is by defining formal comparison and evaluation options, known as metrics. In [11] there are metrics introduced to evaluate SOAs with different abstraction levels. Based on the Quality Attributes, which consists of four of the six quality characteristics of ISO 9126, seven design properties are derived. Five are suitable to evaluate the EM services.

The following five attributes are defined by [12] in this manner:

- Coupling: The degree of dependence between services
- Cohesion: The degree to which the tasks performed by a single software module are related to one another
- Complexity: The degree to which a system's design or code is difficult to understand because of numerous components
- Design Size: The size of a system
- Service Granularity: The depth or level of detail at which data is represented in a service

The remaining two, parameter granularity and consumability are not used. Both are connected close to the implementation and should be taken into consideration when implementing the concept.

The metrics in

Table *1* for these five attributes are taken from [11] with minor changes to adapt it to the EM system introduced in this paper. Therein $n_{S,C}$ is the number of connected services, n_S the total number of services, $n_{M,U}$ the number of used messages, n_F the number of functions and n_M the number of messages.

Table 1: Design metrics for a SOA and their characteristics in the energy management service according to [11]

Design Property	Derived Metrics	Characteristic in the EM
Coupling	$\frac{n_{S,C}}{n_S}$	↑
Cohesion	$\frac{n_S}{n_{M,U}}$	↓
Complexity	$\frac{n_S}{n_F}$	↓
Design Size	n_S	↓
Service Granularity	$\frac{n_M}{n_S}$	↓

Without the service architecture of the entire vehicle, it is not useful to evaluate the EM separately, but a first estimation is possible. It is responsible to supply all electrical consumers so every system that manages functions, needs to request power. It is therefore connected to the consumers by the power demand and allocation services. The remaining services may not have many connections, mainly systems for managing the autonomous driving on the guarantee side and the ESS on the requirement side, accordingly, the coupling is high. Therefore the cohesion is low as the number of unused messages is increased. This is due to the allocation guarantee, which sends all of the information to all registered consumers. The complexity of each system is mainly derived by the number of its services, to make it comparable with other concepts, it is standardized to the number of functions. In this concept, many services have been put together to reduce their overall amount and most consumers are connected by one requirement and one guarantee, less is not possible when there is a system with controlled consumers. This supports a low complexity compared to other systems. The design size is directly linked to the number of services and therefore is low too. Service granularity is defined as the relationship between the number of messages and services. The introduced EM concept uses only a few services besides the necessary power demand and allocation. The remaining services could be summarized to one, but this would decrease the cohesion which results in lower effectiveness and reusability. Other concepts might have a higher service granularity or better results in single aspects, but the system optimum is always related to the prioritization of the criteria by the designer and customer.

For the validation of the modularity, the model can be checked with the help of the connected system. If technical solutions of them cannot operate with or do not fit in the services of the designed system, it must be redesigned or the system boundaries adjusted.

3 An approach to determining the data quality for a service-oriented energy management

The five levels of automation defined by SAE J3016 assume the necessity of a driver for the levels one to three. For level 4 and 5 the vehicles consequently has to fulfill all previous tasks of the driver. Additionally, to level three this includes a fallback operation in case there is an error. Furthermore, the steering of the vehicle must be adapted to the environment and vehicle situation. [13]

For both of these, the vehicle needs a self-perception that monitors at least all safety-related functions, compares it to the driving situation, and adapts its behavior. A requirement for these tasks is that services provide the quality of their data, so the automation and self-perception can identify limited validity. Therefore they can react by adapting their behavior or changing the data source. The ASOA introduced in [9] considers this quality aspect in its structure, but how the quality for each service should be determined remains unclear. This is caused by the aspect, that the assessment of the data quality is highly function-dependent, which makes it difficult to define a uniform approach. In Figure 4, an overview of the data quality calculation for the internal use of the EM service and its guarantees is given. The data quality has to be assessed to determine if the data is reliable and which data can be used. This can be done by monitoring the system inaccuracies and evaluating their impact. Further aspects are the influence of the dynamics caused by the driving profile and the time criticality. Furthermore, it should be considered how the data was determined e.g. calculated by a model or measured by a sensor. Every service should do the data quality calculation by itself otherwise coupling between them will cause lower modularity and flexibility.

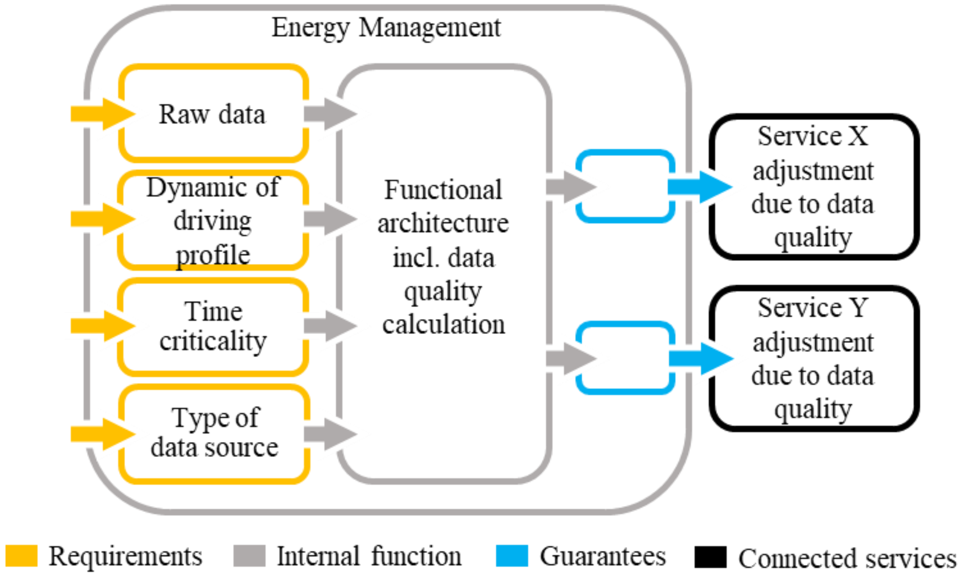

Figure 4: Data quality calculation for internal and guarantee specific use

Many publications deal with the topic of determining the data quality e.g. [14], [15], [16] and [17]. The criteria for evaluating the data quality are highly dependent on the application, for the ASOA the aspects validity, reliability, and ageing are, most suitable. All of them evaluate the various interpretations of different characteristics, summarize them and highlight the most significant. It is not helpful to put all aspects into one variable as data quality and accuracy have a completely different impact, but both are helpful for automation. To find out which data source should be preferred in case there is more than one, the system uses the data quality. The impact of the data is evaluated by its accuracy.

The data quality ε_{DQ} is determined with eq. (1)

$$\epsilon_{DQ} = P \cdot R. \tag{1}$$

With P as the output of the plausibility check and R as the reliability index. The plausibility check compares the values of different data sources e.g. various sensors and calculations, and checks their compatibility. In case the combination of the values is plausible, the output is one, else it is zero. The reliability index considers the influence of the dynamic load profile on the measurement. A highly dynamic load will affect the different physical dimensions of the vehicle battery e.g. the battery voltage will drop or raise immediately when there is a charge or discharge current. The battery temperature on the other hand will change much slower in the same scenario. Furthermore, the temperature sensor position in the battery pack influences the measurement as well. An increasing distance will cause a higher time delay and measurement offset. Physical dimensions that are in relationship with the battery load are less reliable when the profile is more dynamic. Therefore a reliability characteristic curve dependent on the elapsed time and the load for each dimension is required. One approach for defining the reliability function is to carry out experiments and simulations with the measured and calculated values. The reliability index R is determined with eq. (2). Where S is the trustworthiness of the data source with a range of zero to one. If the value corresponds to zero, the source is unreliable. For a value of one, the maximum reliability can be assumed. τ is the time constant that the measured signal has at a specific position and variable and τ_{Min} is the minimum time constant for a specific variable.

$$R = \frac{S \cdot \tau_{Min}}{\tau} \tag{2}$$

The accuracy of the data Δ_{ACC} is calculated with eq. (3)

$$\Delta_{ACC} = \Delta_M + \Delta_A. \tag{3}$$

It has the dimension of the measured signal. Δ_M as measurement variance and Δ_A as ageing variance.While Δ_M is mainly caused by the sensor inaccuracies, Δ_A is a prediction of the maximum change over time. The worst-case estimation for temperature, voltage, and SOC due to the time-dependent change is obtained from eq. (4), (5), and (6)

$$\Delta_{A,T} = \frac{\dot{Q}_{max} \cdot \Delta t}{m \cdot c} \tag{4}$$

$$\Delta_{A,U} = U_{t=0} + I_{max} \cdot R_{Bat} + \frac{\Delta W_{el}}{I \cdot \Delta t} \tag{5}$$

$$\Delta_{A,SOC} = SOC_{t=0} + \frac{1}{C_N} \cdot I_{max} \cdot t \cdot \eta_{Bat}. \tag{6}$$

With maximum heat flow Q_{max}, time difference Δt, mass m, specific heat capacity c, battery voltage U, battery current I, battery internal resistance R, electrical work W_{el}, state of Charge SOC, nominal capacity $C_{N,}$ and coulomb efficiency η_{Bat}. . It is assumed, that for current, SOH, SOF there is no relevant aging effect or estimation is not meaningful.

The calculation of the data quality is shown in Table 2 with two temperature sensors. One is located on top of the battery cell surface (T1), and the other one is in the cooling outlet of the entire battery cooling system (T2). For the reliability, a minimum time constant of 1 second is assumed as this is accomplished by T1, while T2 has a time constant of 20 seconds. The trustworthiness of T1 is 1 as it is the most reliable sensor for the battery temperature. T2 has a trustworthiness of 0.8 because it is a real measured signal but has a time delay and provides no information about a single battery, only about the overall temperature. Calculated signals might have a lower trustworthiness. Following this example the energy management would choose cell surface sensor T1, because of the higher data quality ε_{DQ}. The accuracy of the data Δ_{ACC} is a worst case estimation in case there is no new signal in a period of 30 seconds.

Table 2: Data quality of two temperature sensors

Data Quality	Cell surface sensor T1	Cooling outlet sensor T2
P (-)	1	1
R (-)	1	0,04
ε_{DQ} (-)	1	0.04
ΔM (K)	0.3	0.5
Δ_A (K)	0-8,79 (0-30 s) [18], [19]	
Δ_{ACC} (K)	0,3-9,1	0,5-9,3

Conclusion

The current endeavor towards autonomous driving and digitalization in the automobile industry requires crucial changes in the E/E-architecture of vehicles. The architecture needs to become more flexible to be able to adapt to its environment. At the micro-level, this affects the vehicle itself, which must adapt to changing driving situations. At a macro level, vehicle architectures need to be flexible to be adapted and updated during their product life cycle. One essential part of a modular structure is the communication between different systems or their services.

Based on the ASOA, a service-oriented architecture for the UNICAR*agil* vehicles, the concept of a service-oriented EM is designed. A decisive change to previous systems, besides the SOA, is the cooperation with the automation and the self-monitoring of the vehicle. The control of the safety-related functions and the decision about the trajectory is done by the automation. The EM supports these decisions by providing information about the available power and remaining energy. The non-safety-related tasks are controlled by the EM depending on the remaining power and the users' demands. The service structure is evaluated on metrics from [11], which are adapted and applied to the concept. It shows high modularity and flexibility as intended by the SOA, but related some disadvantages when it comes to necessary bandwidth for the data transmission as in some services a lot of unused messages may be received by the consuming software components. The problem can be fixed by applying the concept to a real system and identifying an optimum between service granularity and available bandwidth. Furthermore, we have presented a concept for the data quality evaluation of a service-oriented EM by comparing two differently placed temperature sensors and the influence of the location on the data quality.

Acknowledgments

This research is accomplished within the project "UNICAR*agil*" (FKZ 16EMO0289). We acknowledge the financial support for the project by the Federal Ministry of Education and Research of Germany (BMBF).

References

[1] L. Brandt, *Archtekturgesteuerte Elektrik/Elektronik Baukastenentwicklumg im Automobil*, p. 87-91, Technische Universität München, Lehrstuhl für Produktentwicklung, 2016

[2] D. Scott, U. Hoff*, Solving the E/E dilemma of electric and autonomous vehicles*, Siemens Digital Industries Software, https://www.plm.automation.siemens.com/media/global/en/White%20Paper%20-%20Siemens%20SW%20Solving%20the%20EE%20dilemma%20of%20electric%20and%20autonomous%20vehicles%20WP-latest_tcm27-69007.pdf, 2019

[3] H. Banvait, S. Anwar and Y. Chen, *A rule-based energy management strategy for Plug-in Hybrid Electric Vehicle (PHEV)*, 2009 American Control Conference, 2009, pp. 3938-3943, doi: 10.1109/ACC.2009.5160242

[4] A. Becker, *Nutzenpotenziale und Herausforderungen Service-orientierter Architekturen*, ISBN 978-3-8349-6228-7, Wiesbaden, Gabler Verlag, 2011

[5] Wagner, Marco & Zöbel, Dieter & Meroth, Ansgar. (2011). *An adaptive Software and Systems Architecture for Driver Assistance Systems based on service orientation*. International Journal of Machine Learning and Computing. 1. 359-366. 10.7763/IJMLC.2011.V1.53.

[6] T. Böddeker et. Al., *Skalierbarer modularer Strukturbaukasten: Von der Anforderungsermittlung bis zum Hardwareaufbau*, Online [Access: 15-03-22]: https://www.unicaragil.de/hzevent#Strukturbaukasten, 2020

[7] M. Goth et. Al., *A Novel Electrical Energy Management System in Automated Battery Electric* Vehicles. In: 33rd Electric Vehicle Symposium (EVS33), Portland, Oregon, June 14 - 17, 2020

[8] M. Buchholz, et. Al., *Automation of the UNICARagil Vehicles*. In: 29th Aachen Colloquium Sustainable Mobility 2020, Aachen, 2020

[9] A. Kampmann et. Al., *A dynamic service-oriented software architecture for highly automated vehicles*. In: 2019 IEEE Intelligent Transportation Systems Conference, ITSC 2019, Auckland, New Zealand, October 27–30, 2019, pp. 2101–2108. IEEE (2019).

[10] A. Basler, *Eine modulare Funktionsarchitektur zur Umsetzung einer gesamtheitlichen Betriebsstrategie für Elektrofahrzeuge*, Dissertation, Karlsruher Schriftenreihe Fahrzeugsystemtechnik, Band 42, 2015, doi: 10.5445/KSP/1000048340

[11] B. Shim, S. Choue, S. Kim and S. Park, *A Design Quality Model for Service-Oriented Architecture*, 2008 15th Asia-Pacific Software Engineering Conference, 2008, pp. 403-410, doi: 10.1109/APSEC.2008.32.

[12] International Organization for Standardization, "ISO/IEC/IEEE 24765:2010 - Systems and software engineering -- Vocabulary," ISO/IEC/IEEE, 24765, Dec. 2010.

[13] SAE International 2016. SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

[14] C. Fox, A. Levitin, T. Redman, *The notion of data and its quality dimensions, Information Processing & Management*, Volume 30, Issue 1, 1994, Pages 9-19, ISSN 0306-4573

[15] T. Busert and A. Fay, *Information Quality Dimensions for Identifying and Handling Inaccuracy and Uncertainty in Production Planning and Control*, 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA), 2018, pp. 581-588, doi: 10.1109/ETFA.2018.8502465.

[16] Cai, L. and Zhu, Y., 2015. *The Challenges of Data Quality and Data Quality Assessment in the Big Data Era*. Data Science Journal, 14, p.2. DOI: http://doi.org/10.5334/dsj-2015-002

[17] Leo L. Pipino, Yang W. Lee, and Richard Y. Wang. 2002. *Data quality assessment*. Commun. ACM 45, 4 (April 2002), 211–218. DOI: https://doi.org/10.1145/505248.506010

[18] Schlereth L.-E., *Auswahl von Lithium-Ionen Zellen für die Traktionsbatterien von Elektrofahrzeugen unter Berücksichtigung thermischer Einflüsse des gesamten Antriebsstranges*, Fakultät für Maschinenwesen Technische Universität München (TUM), 2018

[19] Uptmoor F., *Modellbildung und Simulation von Batterien in der Elektromobilität*, Hochschule für Angewandte Wissenschaften Hamburg (HAW) Fakultät Technik & Informatik, 2011

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