Electric Mobility: Chances and Technical Challenges

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1. Introduction

Today's economy has to face the challenge of finding solutions to megatrends like the urbanization, demographic shift, connectivity, mobility and growing ecologic thinking. From a present-day perspective electric mobility seems to be one of the key technologies of the future as it can solve many of the occurring problems. About 80% of the worldwide CO2 emissions stem from large cities and their metropolitan areas[1]. The transport sector alone participates in the worldwide emissions with 20%[2]. Rapid urbanization and the creation of so-called mega-cities place new requirements on the old automobile paradigm. Pollution, noise and traffic congestion are an ever-growing problem in the bustling metropolises. The transition to renewable energy sources offers many chances and challenges for the automotive industry. The clean energy comes with a certain cost involved in refining the load balancing, energy distribution and handling of many heterogeneous energy producers on the local and global scale. This is a window of opportunity for business concepts which connect the energy producers' issues with the automotive-specific battery-cost issue. An average automobile spends 90% of its time standing still. This time period can be used to actively participate on the dynamically priced energy market and to stabilize the external energy network through the vehicle's battery. Large parking lots can therefore become significant actors on the energy market and create a large virtual buffer for all the energy spikes. However, such a business model requires large-scale changes in the existing energy and communication infrastructure.

Electric mobility introduces new challenges for the vehicle producers, since the number of mechanical components in the vehicle is reduced, as well as the aftermarket for all electric vehicle types. In order to implement all the higher-level functionality, a new approach to vehicle ICT architecture is required. This requirement stems from following sources:

- Further increase of functionality in today's vehicle leads to rapid increase of complexity in vehicle's networking and rapid increase in integration costs
- Applications like global energy management or autonomous driving require access to a wide-range of vehicle subsystems and place heavy requirements on the underlying communication structures

As analyzed in a recent study on future ICT architectures for electric vehicles (1), the shift to electric drivetrain is a chance for a more general overhaul of the entire vehicle communication and computing platform. Therefore, the disruptive approach of new electric vehicle concepts including the resulting new value chain holds a great danger potential for conventional vehicles. Mitchell, Borroni-Bird and Burns (11) make a comparison of what makes a conventional vehicle versus what makes a future-ready mobility solution. The main changes are given in Table 1.

[1] IEA World Energy Outlook 2008

[2] IPCC 2007.

Current vehicle	New vehicle
Mechanically driven	Electrically driven
Powered by internal combustion engine	Powered by electric motors
Energized by petroleum	Energized by electricity and hydrogen
Mechanically controlled	Electronically controlled
Stand-alone operation	Intelligent and interconnected

Table 1. Comparsion of the new and the old automotive DNA (19)

With the electric car, we gain a possibility to obtain or even enhance the freedom of the individual in parallel with a sustainable mobility, economic growth and prosperity. This large-scale transformation of personal urban mobility system through technological, design and business innovation is an example of a "wicked problem" (11), (12). Such problems involve a system of highly interdependent systems, with the property that actions taken to improve one aspect of the system may produce unexpected reactions and unwelcome side effects. It requires creative speculation about possibilities, ongoing critical discussion of principles and options, engagement of stakeholders with differing and perhaps conflicting interests, building consensus and coalitions of interest, and responding flexibly to the unexpected twists and turns that emerge along the way to a solution.

In regards to this approach, we provide two relevant excerpts from the executive summary of the study Competitiveness of the EU Automotive Industry in Electric Vehicles by Proff and Killian (9):

On the whole, the total volume of the automotive service sector is likely to rise in the coming years, as the two automotive power devices (traditional engine and electric battery) will and exist and have to be serviced in parallel. For example, the installation of charging and service infrastructures for electric vehicles will be necessary while still retaining the traditional petrol, gas and service stations. Other developments such as the rising number of car sharers because of opportunities offered by the use of small electric vehicles in city centres will increase this trend even further. New opportunities could be offered by services enabling leasing or recharging of batteries. On the other hand, due to the decreasing complexity of electric vehicles in comparison to internal combustion engine vehicles, the after-market will decline in volume.

In this study, an upper- and lower end scenario ("Accelerated Path to Electromobility" versus "Long Run to Electromobility") were developed. The "Accelerated Path to Electromobility" scenario is based on: dynamic growth on the global vehicle market, an increase in the market penetration of electric vehicles up to 2020, rapid technological and business models development and further activities in terms of public policy support. This could lead to an additional EU- 27 value added of approximately 20 billion Euro in 2020, 30 billion Euro in 2030 and the creation of 100,000 to 150,000 new manufacturing jobs in Europe. In the hypothesis that the development of electromobility is slow and the total market - especially in the BRIC countries -develops less dynamically, the European automotive industry's value added would be adversely affected (minus 20 billion Euro by 2020 and minus 40 billion Euro by 2030), leading to a significant loss of 150,000 *to 250,000 jobs. The scenarios show that electromobility is the key to the development of value added and job-creation in the European automotive industry.*

While the efficiency of the electric motor floats around the 90% mark, the efficiency of the internal combustion engine is at 16% (gasoline) and 21% (diesel). The energy consumption of a typical electric vehicle driving at 50km/h is between 4 and 8kW. On top of this, there is an additional 1 to 3kW for cooling and heating systems, between 150 and 350W for lighting and various auxiliaries, 100 to 200W for infotainment devices and 20 to 200W for various controllers. The gas tank in an internal combustion engine (ICE) provides the range of 1000 km with climate control. The typical battery in an electric vehicle provides the range between 150 and 300km without climate control. A Li-Ion battery provides about 200Wh/kg, meaning that 100kg of cells provides 20kWh. The same amount of energy is provided by only 2 litres of gasoline. All this bespeaks maximal efficiency of all aggregates and controllers in the electric vehicle.

Electric motors and batteries can be distributed throughout the vehicle's chassis, providing previously unknown levels of freedom in creating the chassis. Entire electric motors, complete with steering actuators, suspension and brakes, can be integrated in a single wheel. One example of the amount of design freedom gained by using in-wheel motors is the project eCar[3]. High performance in-wheel motors are currently being tested in the Roding eRoadster vehicle by Siemens CT in Munich, with special focus on torque vectoring, regenerative braking and brake blending[4].

2. Consequences for the infrastructure

Considering the energy demand for one year, an average of 80 GW has to be provided continuously to cover the needed power of all vehicles in Germany. The available photovoltaic systems and wind generators together can provide an output of approximately 60 GW. Thus it is theoretical possible to cover the energy demand of the traffic completely with regenerative sources in the near future in Germany. For a practical approach, the energy from the regenerative sources has to be stored until needed. Considering the average capacity of the batteries of current electric vehicles of 20 kWh, one million vehicles are needed for a capacity of just 20 GWh. This means that the contribution of

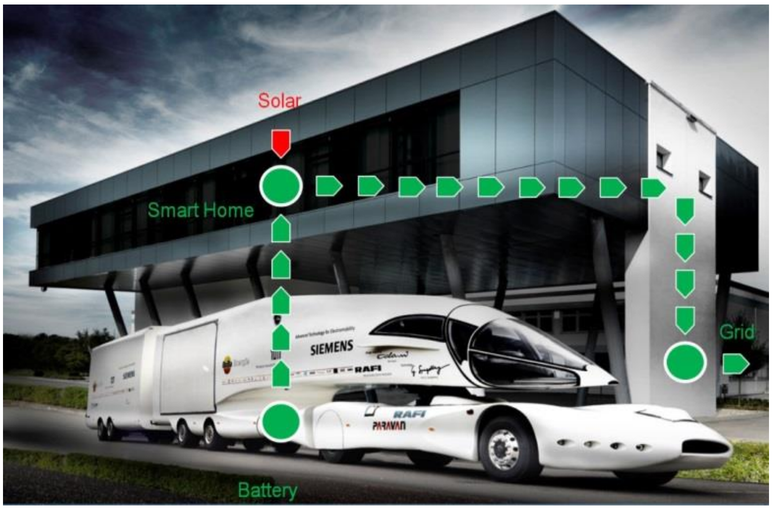

Fig. 1. Electric vehicles can be utilized in a form of a large virtual battery to stabilize the grid.

[3] Project eCar is a cooperation between fortiss and Technische Universität München with the focus on Drive-By-Wire, new vehicle ICT architectures and centralized human-machine interfaces: http://www.fortiss.org/en/research/projects/ecar/

[4] http://www.siemens.com/innovation/apps/pof_microsite/_pof-spring-2012/_html_de/elektroautos.html

vehicles as a distributed energy storage system is negligible and other solutions have to be taken into account.

2.1 Smart grids

Currently, the energy flow is mainly directed from the power provider towards the customer. This leads to bottlenecks if electric cars are connected at private houses as these systems were not designed with that high energy demand in mind.

One solution is to use the energy of adjacent energy cells – i.e. photovoltaic systems or other electric cars – to cover the peak demand at certain hotspots. But this solution depends on two factors: On the one hand, bi-directional charging has to be possible. On the other hand, an infrastructure must be implemented to control the whole system. If both pre-requisites are fulfilled, the energy distribution system can react on local demands and re-route the energy flows. The management of this approach needs a deeply connection between the energy flow and the data flow, making the energy system a “smart grid”.

2.2 Intelligent transport systems

In the previous chapter we have considered connecting the vehicles into the energy infrastructure, which involved a certain amount of data processing in order to participate on the energy market and to stabilize the grid. In this chapter, we go one step further and examine the vehicle not only as an energy system with appropriate energetic states and goals, but as a single sensing unit, a generalized sensor in the overall traffic network. The data collected through the real vehicle sensors, together with the entire set of vehicle states (end destination, current driver assessment, ICT diagnostics), can be forwarded to a higher-order processing system which optimizes traffic flow and increases road safety. Dangers spotted by one vehicle can be disseminated in the affected region, to name one example. In an extreme case, the higher-order system can take control of the vehicles in danger and bring them to a safe state. The basic operating principles of such systems are similar to ones implemented for autonomous driving, driver assessment or a general situation awareness engine (23).

The first step towards this functionality is standardizing the car-to-infrastructure connection. One option is extending the standards originally created for the semantic sensor web. The semantic web, as envisioned by Tim Berners-Lee and described by the W3C Semantic Web Activity, is an evolving extension of the World Wide Web in which the semantics or meaning, of information on the Web is formally defined (16). These standards, such as Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE), provide geospatial sensor discovery over standardized web interfaces together with plug-and-play addition of new nodes. A minimal subset of the SWE has been successfully implemented and tested in the project Innotruck.

The second step is the selection of the knowledge modeling toolset, which provides a basis for later situation analysis and decision making. This toolset, or better a knowledge framework, should model the already ubiquitous driver-vehicle-environment construct and enable knowledge exchange over the previously standardized car-to-infrastructure connection. Standard issues which are further handled by the framework are uncertainty management, real-time answering of situation-relevant questions and balancing of in-vehicle (embedded) and in-the-infrastructure (in the cloud / on external servers) processing, feature detection and decision making.

3. System architecture for electric vehicles

After the introduction of the anti-lock braking system for vehicles in the 1970s, which was the first system in a vehicle based on digital signal processing, the processing power in the vehicles increased rapidly and ended currently in a highly complex information- and communication technology (ICT) architecture. To be able to cope with the requirements for future vehicles caused by the ever-growing amount of implemented functions, a radical change in the design and deployment process is necessary.

3.1 ICT Architecture in today's vehicles

The lines of code increased from 100 in the 1970s up to as much as ten million lines today (20). Already 90% of the innovations in a car are contributed by software components and it is expected that this trend will continue. The integration effort increases, as the impact of the existing functions gets harder to model and predict. Extensive verification processes with exploding costs are necessary to guarantee the correct functionality.

The existing architecture was extended in an evolutionary process, which ended in cars with heavily distributed subsystems compromised of dozens of electronic control units (ECU's) and various heterogenous bus systems that interconnect them. It is expected that more and more functions are realized with software, which led to several problems in today's vehicles that have to be tackled (16):

- High complexity due to a variety of heterogeneous networks with different characteristics.
- The infrastructure of vehicles was not designed to support purely electronic control i.e. the systems are not fail-operational.
- Advanced driver assistance systems combine data from more and more different sources, which leads to an increased interconnection demand.
- Verification of the system is a challenge, as many electronic components have to be considered simultaneously.
- The system architecture of today's vehicles was not designed to be extendable with modifications after-sale.

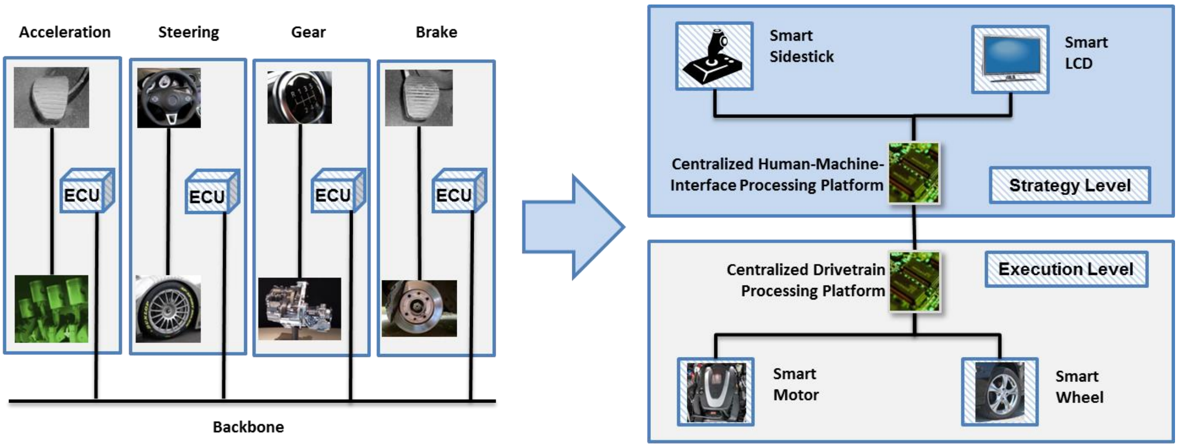

Fig. 2. *Shift from a component-driven design process to a data-driven oriented design process.*

3.2 Paradigm shift

We propose a shift in the design principle of a vehicle's system architecture from a component-driven process towards a data-flow oriented design process. The classic approach, the component-driven process, started in former times with a purely mechanical controlled car, evolved via mechatronic subsystems to interconnected mechatronic subsystems with disttributed functionality. The outcoming architecture reflects the one-ECU one-function principle, which makes it hard to benefit from a deeply interconnection between the different driving functions. For example, in electric cars, the process of recuperation and mechanical braking has to be coordinated with each other but this is a challenge as the systems come as a black-box and have to be interconnected externally which means a high development effort.

The data-flow driven approach instead tries to follow the paths for data processing in the vehicle and is independent of individual components. The functionality is pushed from the physical container of an ECU to software containers where the high-level functionality is executed. Due to the increasing demand for sensor fusion approaches and holistic control strategies distributed system knowledge is not feasible anymore. One realization of this principle is the centralized ICT architecture. Furthermore, the system as well as the connected actuators and sensors have to become smart in order to support composability of the whole system and to make it flexible – before sale and after-sale.

3.3 Centralized ICT architecture

The centralized ICT architecture consists of centralized processing units, homogenous networks and smart components. The functionality is realized as software units on the central processing units that share common resources like processing power, memory and communication bandwidth. For safety-critical systems, the central processing units are designed in a redundant way to achieve fail-operational behavior. These units are interconnected via networks that can guarantee the transmission of data according to quality-of-service requirements of the running functions. The actuators and sensors of the system can be attached to this system in a flexible way by standardized software and hardware interfaces, making it possible to change the functionality of a vehicle after-sale.

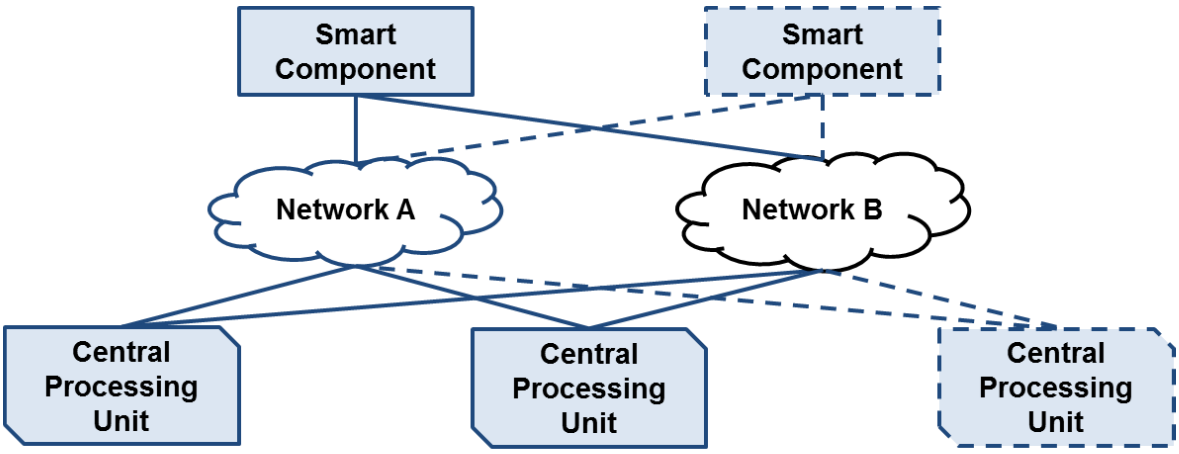

Fig. 3. Components of the centralized system architecture.

One cornerstone of the centralized ICT architecture is a runtime environment that supports functions for the management of software components and to guarantee the correct allocation and partitioning of needed resources. We propose to integrate a set of basic services into this runtime system, which are often needed in future applications. Those services include plug-and-play management for a seamless integration of hardware and software components into the already existing system and a manager for security issues as the future vehicles are going to be more and more interconnected. Thus, it is also important to protect the vehicle from non-physical attacks. Furthermore, a mechanism for automatic data fusion should be able to provide functions to combine the data from several sensors and to provide a consistent output to the applications. A runtime system which implements a basic set of these functionalities was developed as part of the project CHROMOSOME (17), (18), which can be downloaded freely.

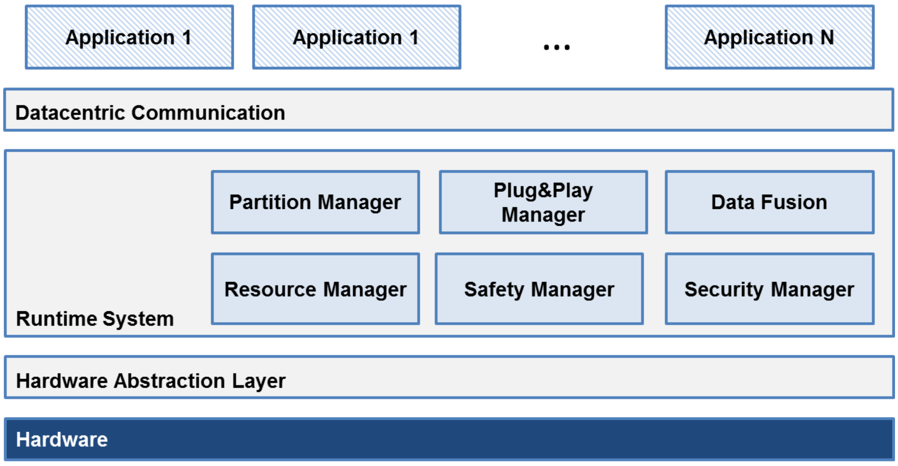

Fig. 4. Runtime environment

The requirements of the applications are described in a data-centric fashion, allowing the expandability of the system via introspection. In the data-centric paradigm, the sender and receiver of data agree on a certain data-type and name – called topic – and a set of quality properties that have to be matched. It is in the responsibility of the runtime system to find suitable matches and configure the system in a way that a data flow is guaranteed according to the requirements. This completely decouples the data sources and sinks in the system and makes it very flexible. For example, an electronic steering wheel following this principle can be easily replaced as the runtime system will match the receivers and enforce the safety requirements.

A key idea of the centralized approach is to use smart actuators and sensors. These components are smart, because they can pre-process the data and run local feedback loops. This is important to reduce the required communication bandwidth as the smart components can interpret the abstract commands sent from the central units and react in a certain range to external changes on their own. An example for a pre-processing smart component is a camera that can extract information out of the image like the position and velocity vector of other vehicles or pedestrians. Instead of sending the complete image, only the list of objects is sent to the central system which reduces the bandwidth demand dramatically. Furthermore, as an abstract representation is chosen, the camera can be exchanged by another one and the functionality of the system does not depend on intrinsic parameters of it like frame rate or resolution.

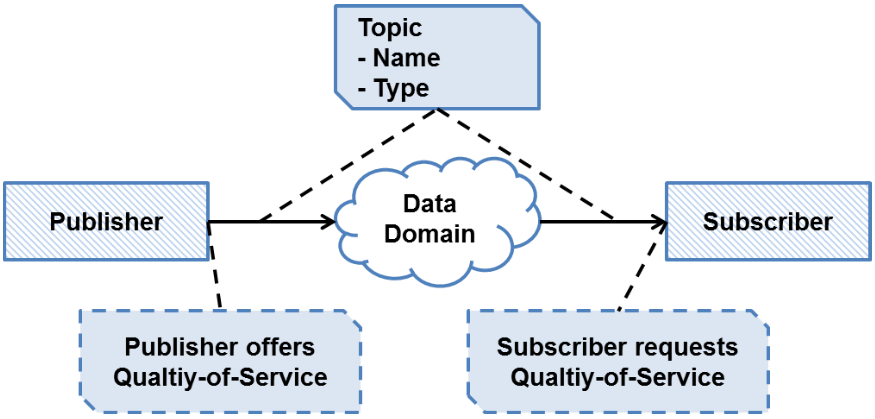

*Fig. **5.** Requirement description in a data-centric way.*

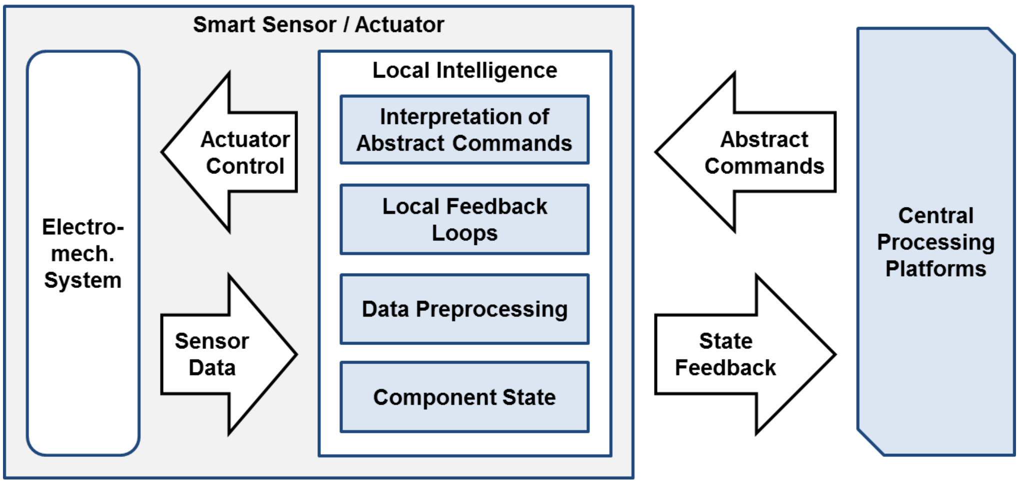

Fig. 6. Smart components.

*Fig.7 **.** eCorner as highly integrated smart component.*

Another example for a highly integrated smart component is the eCorner, which combines the functions for accelaration, deceleration and steering in one module. It consists of one steering motor and one in-hub motor, which are controlled via a microcontroller to form a smart component. The outstanding in this setup is the ability of the eCorner to be controlled by just a few commands that include the direction and torque of movement. The eCorner is responsible on its own to execute this command in an optimal way.

3.3 Impact

The implementation of a centralized ICT architecture is a challenging task but all involved parties will benefit from a change on the long run. For vehicles with combustion engines a disruptive change is necessary – meaning that the manufacturers have to completely alter their supplier chains and processes. Thus, the change towards a centralized architecture is involved with a high risk for the current manufacturers of conventional vehicles. We think that electric mobility can be a shortcut for the proposed architecture as an electric vehicle comes with different demands for the IT infrastructure and the system has to be re-designed in many aspects. This means that e-mobility can be a chance to establish a future proof architecture in form of a centralized ICT approach. Eventually, the following benefits are expected:

- **Environmental benefits:** Due to shared resources on the central processing units, the overall energy demand can be reduced regarding the information processing. Shared communication media reduces the wiring harness and lowers the weight of vehicles.
- **Advantages for manufacturers:** A centralized architecture enables the optimized addition of further functions. This leads to reduced development costs and shorter development cycles.
- **Advantages for costumers:** Due to the dynamic platform management, the end-user will experience a higher flexibility in system configuration with the possibility of functional extensions.
- **Advantages for suppliers:** With the help of standardized interfaces and a resource-aware runtime system, one product can be sold to different manufacturers without the need for modification.

3.5 Migration

As a radical approach, migration strategies have to be provided to industry for a smooth transition to a centralized architecture and its benefits. One possibility is to keep the conventional vehicle architecture intact and to add electronic extensions based on a centralized architecture. In this approach, the information of the steering wheel is imported by sensors, processed and enhanced afterwards, and finally executed by actuators that control the movement of the wheels. A mechanical fallback will establish the traditional control mechanism in case of a failure of the electronics. This system does not necessarily need to be fail-operational which limits the functionality i.e. autonomous driving is not possible, as the driver has to be always responsive in the case of errors.

The InnoTruck implements an on-top approach for the drive-by-wire system. This means that the existing vehicle architecture was kept and extended by an electronic system. As the electronic extension is the only connection to the vehicle mechanics, this system has to be fail-operational as a single fault must not lead to a complete loss of the system functionality. Thus, this system can also be used to implement functions with very high demand for reliability like autonomous driving.

Another migration strategy is to re-define the classic vehicle domains into domains that fit the data-flow. In this way, the internal structures of the vehicle manufacturers can be kept up to a certain degree. One realization of this idea is the 5-module approach, which

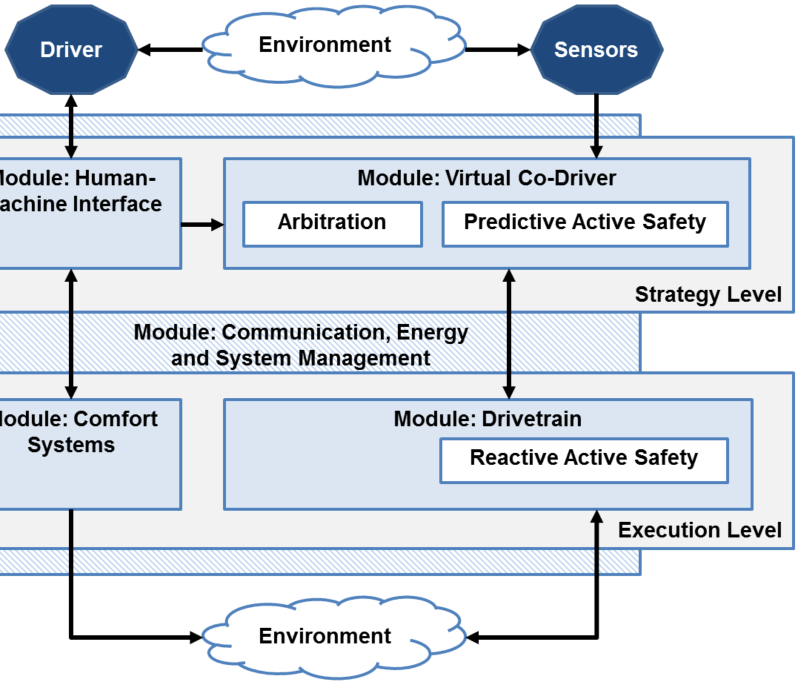

Fig. 8. Data-flow between the functions in the vehicle according to the 5-module concept.

was introduced by Prof. Spiegelberg. It clusters the vehicle functions into the 5 modules human-machine interface, virtual co-driver, comfort systems, drivetrain and system management. It was designed to minimize the inter-module communication in order to optimize the development process. Each module in this approach represents a hardware unit and a business unit at the same time. Starting from this concept, the modules can be further integrated into one physically centralized system while just keeping the clustering on a logical level.

4. Supportive human-machine interfaces on top of the new architecture

We shortly describe the basics of human-machine interaction and how it can be improved in the scope of deeper vehicle changes incurred by the shift to electric mobility. The human-machine interaction is made up of a series of translation steps. One happens at the human side, when his original intent is translated to the speech or movements of body parts in order to convey the command to the machine. The user is also actively involved in the interpretation of machine's feedback. The machine spends some time interpreting the physical and speech input being received through what is currently called a human-machine interface and preparing the feedback through various HMI modalities. At the end, a man-machine interaction has been executed and a task has been performed with a certain degree of quality. The translation involved in the interaction would be more transparent if the machine would process the entire interaction context and if it would interact with the user using complete situation awareness, without forcing a fixed set of interaction rules. The machine feedback would therefore only add to the existing user perceptive abilities and not overlap or overload the user. The level of user support would be adjusted to the user's level of acquaintance with the system and the assessment of the current user fitness.

With this mission in mind, we focus on the following questions in the scope of a road vehicle:

- What are the requirements and the enablers for such situation awareness and for the resulting augmentation of the driver's abilities?
- How can such supportive and cooperative HMI affect the business models around electric mobility?

The new vehicle ICT, described in the previous chapter, provides following key enablers to the supportive and context-aware human-machine interfaces:

- Guarantees on quality-of-service regarding the in-vehicle communication system
- Data-centric approach
- Hardware and software component plug-and-play
- Safe and redundant drive-by-wire system

Having analyzed our mission as well as the enablers provided by the vehicle ICT, we focus on the necessary building blocks.

The preparation of the machine feedback to the driver has to include three stages: context processing, feedback information priorization and, at the end, personalization of the feedback.

The topic of context processing rises following related questions:

- Management of uncertainty
- Embedded performance
- Real-time guarantees
- Ballance of cloud vs. local execution
- Knowledge exchange
- Plug-and-play of new data sources and algorithms

Fig. 9. Personalizable virtual dashboard as an end point of vehicle feedback

The user-vehicle-world construct, together with its inherent uncertainties, can be represented with Bayesian networks. Their exact description, through the rules of conditional probability and associated probability distributions, provides predictability and enables formal testing. We focused on exact inference for the same reasons. Four specific areas for improvement in the HMI domain were identified:

- Inference complexity on embedded hardware
- Separation of conditional dependencies between sensor modalities
- Dynamic addition and removal of data sources
- Time constraints for safety relevant functionality

In the scope of the Innotruck project, an extension of the Junction Tree algorithm, called the Probabilistic Application Layer (PAL), has been developed to improve all the four areas (4). It has been implemented on an embedded platform as a part of a combined HMI - Driver Assistance module inside the 5-Module architecture. As an additional important building block, we also propose a so-called framework for context processing in the domain of human-machine interaction and driver assistance. It builds on top of PAL and fully abstracts its functionality from the application level. The applications can place top-level questions, such as “is there an object which the driver cannot see in the vehicle’s path”, which are parsed and compiled as queries in the PAL together with associated guarantees on inference latency (22).

Priorization of feedback can be rule-based, leaning on road safety regulations, general ergonomic considerations, human perceptive specifics and available HMI devices in the vehicle. Arbitration for limited HMI resources is necessary in the case of conflicting feedback channels. We do not focus on this aspect of the interaction.

Stored user profiles can not only contain the preferred steering sensitivity or interface skin, but also the description of the driver’s skill level, in order to consistently deliver the preferred level of assistance. This level can stay unchanged throughout different vehicle types. In this way, for example, new users or elder population can be gradually integrated into semiautonomous or autonomous vehicles. It is advisable to continuously present the next system step or system state, to attain user’s trust at the beginning. The user should be aware that the vehicle perceives all the objects in its path. Once the trust has been built, the HMI can switch to infotainment content and a minimal representation of the driving task. Our maneuver and parking assistant, which comes with an offline training mode, is one of such assistive systems with varying levels of support. It is possible to adapt the entire suggested parking maneuver to the driver’s acquaintance level, by penalizing difficult mid-actions, like driving backwards with a steep steering angle. Several screenshots of the application are given in Figure 10.

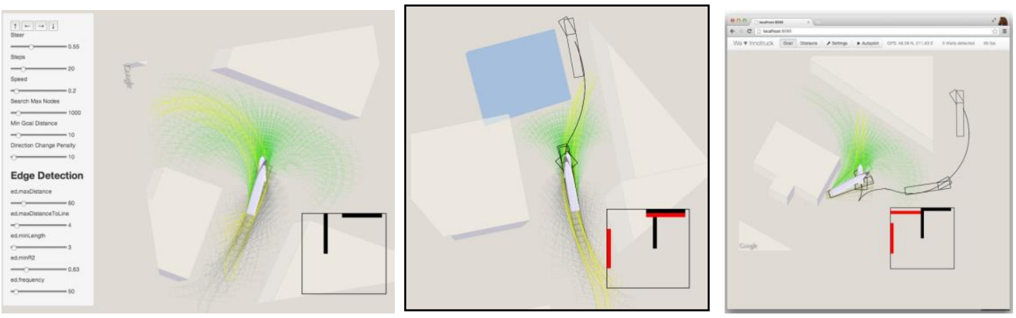

Fig. 10. Adaptable park- and maneuver assistance in Innotruck

Building upon the safe implementation of drive-by-wire, new input methods for primary vehicle control are possible. We considered the highly integrated devices, requiring minimal footprint inside the vehicle and enabling longer operation without physical strain on the user. One of them is the spherical sidestick, test-proven in the area of vehicles for people with physical disabilities, preventing them to operate a standard steering-wheel/gear shifter/pedal interface paradigm. Such device was tested in the Innotruck vehicle, as shown in Figure 11. A standard joystick device has been used as a sidestick in the eCar project.

Fig. 11. Sphere sidesticks integrated in the driver's seat

5. Current projects

5.1 Diesel reloaded

The project Diesel Reloaded is organized by the Institute for Advanced Study (IAS) and the International Graduate School of Science and Engineering (IGSSE) of the Technische Universität München, together with the industry partner Siemens AG. The project started in 2011 and is led by Prof. Dr.-Ing. Gernot Spiegelberg, a Rudolf Diesel Senior Industry Fellow at the IAS and the head of concept development for electric mobility at Siemens Corporate Technology. The principal investigators are Prof. Dr.-Ing. habil. Alois Knoll from the Chair for Robotics and Embedded Systems and Prof. Dr.-Ing. Markus Lienkamp, from the Chair for Automotive Engineering. Three doctoral candidates are active in three research areas. Dipl.-Ing. Claudia Buitkamp is responsible for the vehicle's energy management. Ljubo Mercep, M.Sc,. is working in the field of human-machine interfaces. Dipl.-Ing. Hauke Stähle is developing the system architecture. The interdisciplinary approach is focused on three different aspects of electric mobility: business models, enabling technologies and communication of science to public.

Fig. 12. The prototype vehicle - the Innotruck.

The Innotruck is the project's scientific prototype and the demonstrator at the same time. It is a hybrid diesel-electric drive-by-wire truck with a bionic design from Prof. Luigi Colani. Observing it from the outside, three basic segments can be identified: The self-contained drivetrain, the large semitrailer and the trailer. The semitrailer is internally composed out of three functional segments: Driver's workplace, business lounge and presentation area. The driver's workplace features a highly integrated human-machine interface consisting of a driver's seat with two spherical sidesticks and a central console with the virtual dashboard. The business lounge is outfitted with ambient lighting control and presentation displays. The presentation area is equipped with four large interactive presentation displays.

5.2 eCar

The eCar (19) was designed as a flexible platform to evaluate different approaches for the ICT in electric vehicles. It features four eCorners that can be controlled independently. Two eCorners are connected to form a smart axle. The smart axle is able to execute the command coming from the central processing unit autonomously. It only needs information about the current driving mode and the desired motion vector. Thus, the eCar is a demonstrator for a vehicle where the centralized ICT architecture was completely implemented.

Fig 13. eCar - experimental platform for e-mobility concepts.

6. Conclusion

The shift to electric mobility carries the potential to radically reshape the value creation chain in the automotive sector. Overlapping of the transport, communication and energy sectors could result in creation of new business models, requiring novel technologies and competences. We claim that these will be revolving around three focal points: connection to the infrastructure, vehicle ICT architecture and human-machine interaction inside the vehicle. In this paper, we analyze these topics in-depth and present our findings gained through requirements analysis and prototype development. We present the key enabling technologies and competences necessary to exploit all the chances offered by an expected disruptive market change. The mobility partner of the future is a "vehicle" for data processing, data mining and data exchange. The new vehicle concepts have to provide a suitable runtime environment for new HMI and driver assistance applications. We claim that the electric vehicle is not just a use-case for the new Industrie 4.0 and for the product lifecycle management of the future – supportive and integrated mobility is a chance for itself.

References

(1) Buckl C., Camek A., Kainz G., Simon C., Mercep Lj., Staehle, H., and Knoll, A. (2012) The software car: Building ICT architectures for future electric vehicles. In Electric Vehicle Conference (IEVC), 2012 IEEE International, Greenville, USA.

(2) fortiss GmbH, The software car: Information and communication technology (ict) as an engine for the electromobility of the future, Tech. Rep., Munich, Germany, 2011.

(3) Mercep, Lj., Spiegelberg G., Knoll, A., A case study on implementing future human-machine interfaces. In The 2013 IEEE Intelligent Vehicles Symposium, Gold Coast, Australia, 2013.

(4) Mercep, Lj., Spiegelberg, G., Knoll, A.,Context processing for human-machine interface, Science and Information Conference 2013, London, UK, 2013.

(5) Christian Buckl, Bernhard Schätz, Marcus Fehling, Karl-Josef Kuhn, Cornel Klein et. al. Mehr Software (im) Wagen: Informations- und Kommunikationstechnik (IKT) als Motor der Elektromobilität der Zukunft. Abschlussbericht des vom Bundesministerium für Wirtschaft und Technologie geförderten Verbundvorhabens "eCar-IKT-Systemarchitektur für Elektromobilität", 2011

(6) Fraunhofer ISI, Gesellschaftspolitische Fragestellungen der Elektromobilität, 2011

(7) Geisberger, Eva, and Manfred Broy, eds. agendaCPS: Integrierte Forschungsagenda Cyber-Physical Systems. Vol. 1. Springer, 2012.

(8) P. Albertus, J. Couts, V. Srinivasan and J. Newman, *J. Power Sources*, 2008, **183**, 771

(9) Heike Proff, Dominik Kilian, Competitiveness of the EU Automotive Industry in Electric Vehicles, Final Report, University of Duisburg-Essen, Chair of General Business Administration & International Automotive Management, December 19th of 2012.

(10) Ljubo Mercep, Gernot Spiegelberg, and Alois Knoll. An approach for embedding the vehicle inside the web-of-things. In International Scientific Conference on Mobility and Transport Mobil.TUM 2013, Munich, Germany, 2013.

(11) Mitchell, William John, Chris Borroni-Bird, and Lawrence D. Burns. Reinventing the automobile: Personal urban mobility for the 21st century. MIT Press, 2010.

(12) Rittel, Horst WJ, and Melvin M. Webber. "Dilemmas in a general theory of planning." Policy sciences 4.2, 1973.

(13) Lefort, Henson, Taylor, "Semantic Sensor Network XG Final Report“, W3C Incubator Group Report 28 June 2011.

(14) Holger Neuhaus, Michael Compton, “The Semantic Sensor Network Ontology: A Generic Language to Describe Sensor Assets”, 2009.

(15) Lujan, J.L.P.; Yague, J.L.P.; Ten, J.E.S.; , "Middleware with QoS Support to Control Intelligent Systems“, The Second International Conference on Advanced Engineering computing and Application in Sciences, October 2008.

(16) Amit Sheth, Cory Henson, and Satya S. Sahoo, “Semantic Sensor Web”, IEEE Internet Computing, July/August. 2008.

(17) Hauke Staehle, Ljubo Mercep, Gernot Spiegelberg, and Alois Knoll. Towards the deployment of a centralized ict architecture in the automotive domain. In Embedded Computing (MECO), 2013 Mediterranean Conference on, June 2013

(18) Kai Huang, Gang Chen, Nadine Keddis, Michael Geisinger, and Christian Buckl. Demo abstract: An inverted pendulum demonstrator for timed model-based design of embedded systems. In 2012 IEEE/ACM Third International Conference on Cyber-Physical Systems (ICCPS), page 224, April 2012

(19) Stephan Sommer, Michael Geisinger, Christian Buckl, Gerd Bauer, and Alois Knoll. Reconfigurable industrial process monitoring using the CHROMOSOME middleware. In The Fifth International Workshop on Adaptive and Reconfigurable Embedded Systems (APRES 2013). ACM, 2013.

(20) Martin Eder and Alois Knoll. Design of an experimental platform for an x-by-wire car with four-wheel steering. In Proceedings of the 6th IEEE Conference on Automation Science and Engineering, pages 656-661. IEEE Press, 2010.

(21) R. N. Charette, “This car runs on code,” IEEE Spectrum, vol. Green Tech, Advanced Cars, Feb 2009.

(22) Mercep, Lj., Spiegelberg, G., Knoll, A. 2013. Context processing for human-machine interface, Science and Information Conference 2013, London.

(23) Mercep, Lj., Spiegelberg, G., Knoll, A. 2013. A robust driver assessment method for the brain-computer interface, IADIS Interfaces and Human Computer Interaction 2013, Prague.

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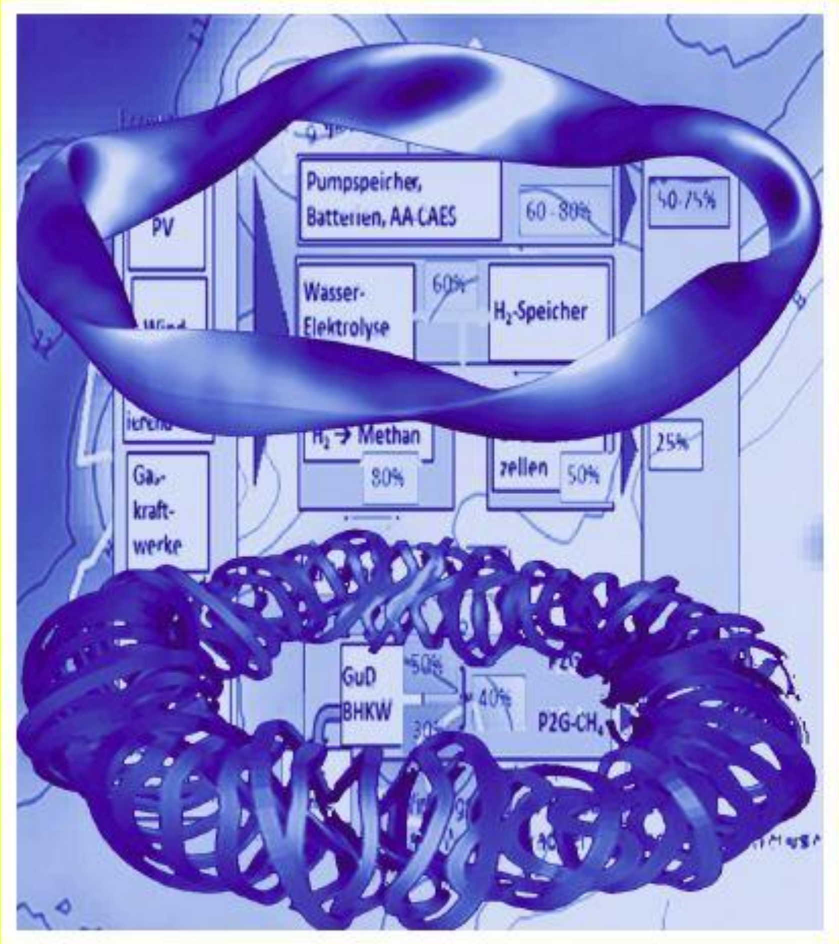

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