Architecture

Over the last three decades, tremendous progress has been made in automotive engineering. Modern injection and exhaust-gas treatment systems drastically reduced pollutants in the exhaust gas, while occupant-protection and vehicle stabilization systems improved safety on the road. Much of this success is due to the introduction of electronically-controlled systems. The proportion of these systems used in cars increased continuously. The requirements of safety and environmental compatibility, but also the demand for comfort and convenience functions, will increase yet further and this will in no small part be achieved through the use of electronics. Up to around 90 % of innovations in the motor vehicle will be realized by electronics and microprocessor-controlled systems. The networking of these electronics creates the prerequisite for having this wide variety of electronic systems integrated within the complete vehicle system to form a whole. However, this results in a complexity that can only be overcome at considerable expense.

Overview

History

The on-board electrical network of a car around the year 1950 comprised approx. 40 lines. Essentially, cables were only required for the battery, starter, ignition and the lighting and signaling systems.

With the first electronic injection and ignition systems, cabling complexity began to increase fast. Sensors fitted in the engine compartment (e.g. speed sensor, engine-temperature sensor) had to deliver signals to the engine control unit, while the fuel injectors required their triggering signals from the electronic control unit.

A further increase in cabling complexity resulted from the introduction and rapid widespread adoption of the antilock brake system (ABS). Meanwhile, comfort and convenience systems, e.g. electrical power-window units, would also form part of the standard equipment. All these systems require additional connecting lines for the connection of sensors, control elements and actuators to the control unit.

1 Proportion of electrics/electronics in the motor vehicle

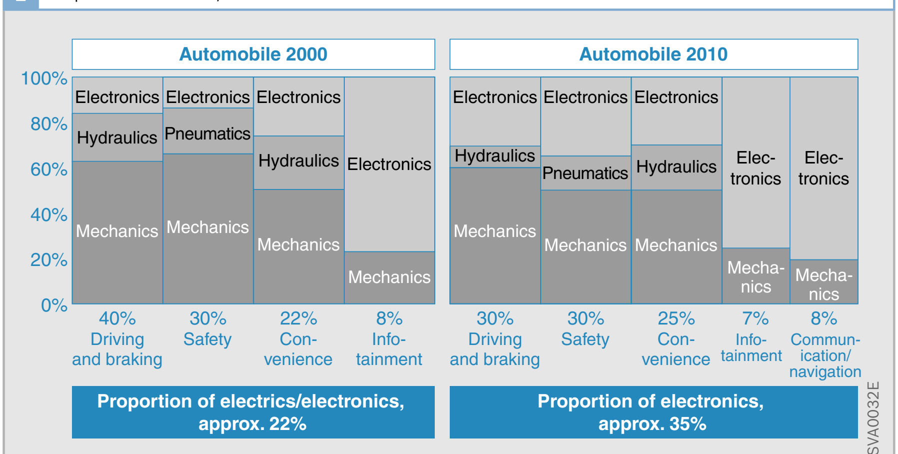

Fig. 1
Source:
Mercer management consulting

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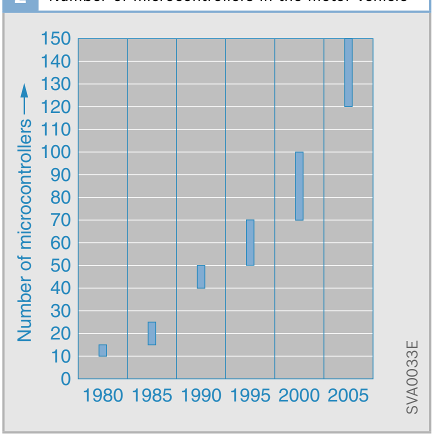
Technology of the present day
In the 1990s the cabling work in a luxury class vehicle amounted to around 3 km. This figure clearly demonstrates how complex the vehicle system has become. The growth of the proportion of electronics in the motor vehicle (Fig. 1) can mainly be attributed to the growth in microelectronics and sensor technology.

At first, many of the new systems were integrated into the vehicle by means of their own dedicated electronic control unit. For the most part, the individual electronic control units operated in mutual independence. All the same, connecting lines became increasingly necessary between electronic control units to enable the exchange of data by means of PWM signals, for example. Depending on the vehicle class, there are between 20 and 80 electronic control units fitted in today's vehicles. They control such equipment as the engine, antilock brake system or the airbags. The number of microcontrollers in the vehicle has therefore risen continuously in recent years (Fig. 2).

The components of the individual systems are optimally matched to each other. The systems may originate from different manufacturers that use previously agreed, albeit still their own, interfaces. The rain sensor, for example, "speaks" in a different way to the sensors for the engine management. The following example demonstrates just how networked the functions in a modern vehicle are: the radar sensor of the adaptive cruise control system (ACC) measures the distance to the vehicle traveling in front. If this distance is shorter than a specified minimum distance, the ACC electronic control unit sends this information to the engine management, the ESP electronic control unit and the airbag electronic control unit. The engine management reduces torque and thus driving speed. If this is not sufficient, the electronic stability program (ESP) must also generate brake pressure to decelerate the vehicle. If the distance continues to shorten, the airbag and seat-belt pretensioners are set to emergency standby. The communication between the electronic control units cannot take more than fractions of a second. The more electronic control units interact in the one complete system, the more difficult it becomes for them to communicate undisturbed.

With the number of electronic control units and the associated need for mutual communication, the costs of developing the systems rose as did the adaptation costs for making interfaces compatible. With the CAN bus (Controller Area Network) developed by Bosch, a powerful and widely used data bus system has become commonplace in vehicles for the first time. The data line of the CAN bus makes it possible for the electronic control units to exchange specific and relevant items of information with each other. At the start, the network only comprised a few electronic control units, such as the engine-management system, the electronic stability program and the transmission control. Gradually, further systems would expand this network, especially in the areas of comfort and convenience and infotainment. The CAN bus has gradually evolved into the standard for networking systems in the motor vehicle. Today it is the standard for communication between elec-

2 Number of microcontrollers in the motor vehicle



tronic control units within different areas of the electronics (drivetrain, suspension, body electronics and infotainment) and forms a powerful backbone for networking these areas with each other. Additional bus systems (e.g. LIN bus, MOST bus) are used as subbuses or for transmitting at high data rates with comparatively low realtime requirements in the motor vehicle.

Development trends

The proportion of electrics and electronics in the motor vehicle will continue to increase. In the drivetrain, the number of components in the exhaust line (e.g. exhaust-gas sensors) is increasing due to stricter exhaust-emissions legislation. While the demands for reductions in fuel consumption can, for example, be fulfilled by means of new valve-gear concepts, even this requires additional electronic components. A further increase in the proportion of electronics results mainly from the growth of electronic systems in the areas of safety, comfort and convenience, and infotainment.

Objectives

Drivers demand a high level of reliability from a car. The vehicle manufacturer and the supplier of assemblies, meanwhile, are constrained by other requirements such as minimization of manufacturing costs, space restrictions and the weight of components. An opportunity to fulfill these requirements in the face of the increasing complexity of the “vehicle” system is seen in the shift of the traditional implementation technologies of mechanics, hydraulics and electrics towards microprocessor-controlled, electronic systems. For this reason, the development of software will continue to gain in importance in future.

The current situation in the electrical and electronic architecture of motor vehicles is characterized by an increase in functionality and an increasingly strained costs situation. To achieve both of these objectives simultaneously, development partners are more frequently tapping into resources that are already available in subsystems. These can be sensors or actuators as well as realized functions that are available to different systems over the communications network. For new systems and functions, manufacturers strive to get by on a minimum of additional resources.
In the meantime, engineers are faced with a new challenge in the form of "networked" thinking and subsystem integration, especially when the assemblies for the subsystems originate from different development partners (suppliers).

Complaints in the field (i.e. with series-production vehicles) due to electrical or electronic failures could be the consequence of not having taken the interactions of the subsystems into consideration. The causes – unmanageable behavior of functionality spread among networked systems, and their integration – are avoidable through the logical application of certified development processes as early as in the specification phase. Furthermore, modeling and tools for authoring a formal description of architectures are gaining ever more in importance.

Broadened requirements for a complete motor vehicle system in the future are leading to increased networking of vehicle components and subsystems. In this regard, new functions are being developed that go beyond the frontiers of traditional applications – and this is without additional expenditure on hardware wherever possible.

New development methods and technologies are required to make this achievable. With a top-down approach, new functions are viewed from the perspective of the complete vehicle. This means that, in accordance with the method of systems engineering, functional requirements and non-functional requirements (e.g. quality objectives, safety, costs, etc.) are set for the vehicle as a whole and derived as specifications for the subordinate subsystems. These requirements are formulated as a model and can thus be used as a specification for the subsystems and the creation of test cases. This is what is known as an “executable specification”, which makes it possible to prove the completeness and the traceability of the requirements, for example, or to identify the requirements for interaction and communication between subsystems. In this way, it is possible to form an optimized architecture for the complete vehicle and its subsystems and components. The functional relationships between the complete motor vehicle system and the subordinate subsystems can be surveyed in different levels of detail and suitable interfaces can be defined for the functions. This approach supports an expanding networking of functions. Synergies are exploited between vehicle areas (domains such as the drivetrain, interior, infotainment) that were hitherto considered in isolation and resources are spared.

As an element of the development process that works in the opposite direction, the generation of new functions from available resources and existing systems (bottom up) should also be taken into consideration to minimize innovation risks. This is how new functions are integrated into existing systems, for example. Examples of this approach are measures to avert the consequences of an accident by “preparing” subsystems for an imminent crash (closing windows, closing the sliding sunroof, activating the airbag, etc.) or the assistance of the driver in emergency braking situations in ESP in future. In this way, it is possible to reduce the number of electronic control units and counteract rising system costs.

The development process described characterizes the CARTRONIC® concept that Bosch developed in the 1980s. The results of this concept are being incorporated into the Autosar Initiative (see Autosar Initiative)

Vehicle system architecture

Architecture

The architecture of a system represents its “construction plan”. It describes the structural and dynamic system characteristics as a whole. The architecture is usually specified in a description language. Special draft mechanisms are used for specific requirements. With architecture being a construction plan for different realization technologies and a means of proving that functional and nonfunctional requirements have been fulfilled in the system draft, different views of the system architecture are required. Examples of this include:

- Hardware architecture
- Software architecture
- Network architecture in the area of realization technologies
- Cost and resource consumption in the area of economical analysis and
- For the area of social requirements, aspects such as safety, availability and legal conformity

The problems that arise in the integration of differently structured subsystems can be reduced by means of an architecture.

Functional structure

The domain of vehicle motion has the task of ensuring the controlled movement of the vehicle as well as its directional stability. This task can be subdivided into various levels (Fig. 3).

The navigation level is home to the planning tools for the driving route. These are merely informational in nature and have no interventional influence on vehicle motion.

At vehicle guidance level, the decisions of the driver are implemented by means of the steering wheel and accelerator pedal but also various assistance systems for vehicle handling (e.g. ACC, course stability systems). At this level, the driver is able to overrule the assistance systems at any time.

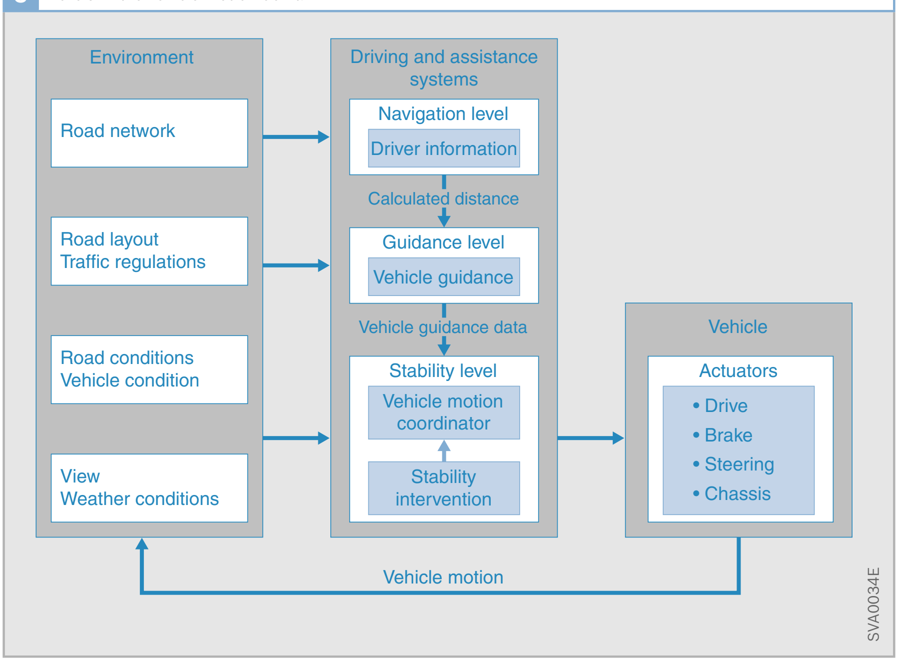
At the stability level, there are the subsystems that are able to correct the decisions taken at handling level if these happen to be outside the range of safe reference variables (e.g. ABS, ESP). This may be the case when cornering or on wet road surfaces, for example.

At stabilization level, correcting variables for implementation by the vehicle's actuators are determined. Information about the environment (e.g. road condition, air temperature, rain sensor signal) is still required at the various levels for the implementation of the relevant tasks.

These tasks can be assigned to functional components, which are the architectural elements of the functional architecture. In this way, the driver information functional component represents the tasks of the navigation level, which are to inform the driver of the driving route determined by means of a mapping system (Fig. 3). Vehicle guidance represents the guidance level, and stability intervention the tasks of the stabilization level. The vehicle motion coordinator determines the correcting variables for the actuators, e.g. of the drive and electronic stability program (ESP), from the information input by vehicle guidance and stability intervention.

Figure 4 shows how the functional components of guidance level, stabilization level and vehicle actuators are related in a hierarchical structure within vehicle motion. Communication relationships between the components and interactions with other domains, e.g. body and interior, are also featured in the model.

3 Levels in the vehicle motion domain



In the same way as Vehicle motion is refined, these functional components require further detailing until the refined components represent manageable, clearly delimited tasks that make flexible, modular implementation possible through different realization technologies. Defined interfaces between the components enable communication and the exchange of data. For example, the transmission control issues a request through the engine-management system for a specific reduction in torque during a gearshift. This value is exchanged as a physical variable via the interface.

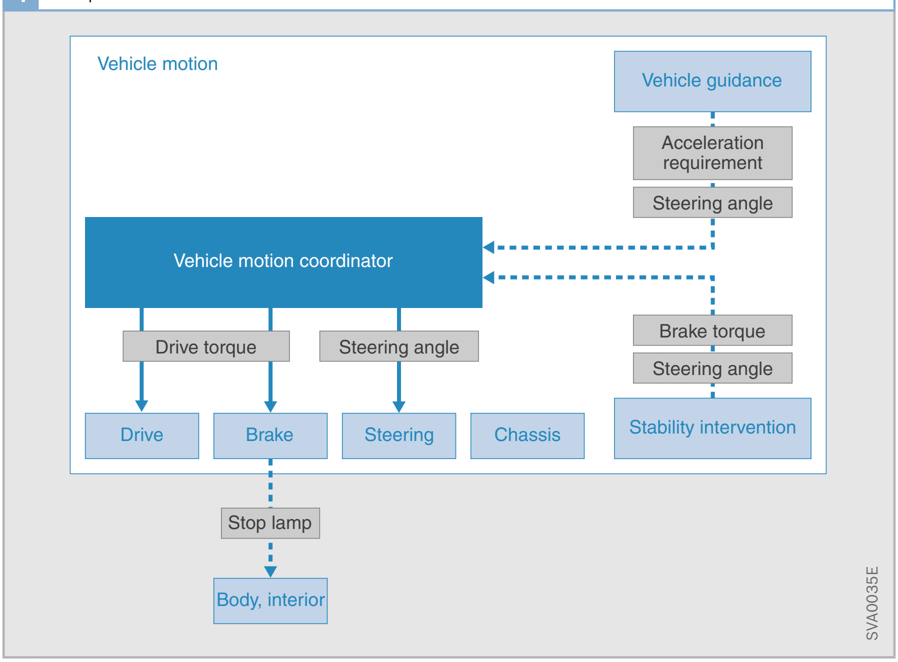
With its integration into a suitable procedural model, the functional structure is the starting point for subsequent stages in the development process.

Systematic creation of EE system architectures

The increasing amount of networking in traditional vehicle domains for the realization of new functions can be illustrated using the ACC (Adaptive Cruise Control) driver-assistance system as an example. Adaptive, same-lane driving is made possible by the networking of a combined cruise and distance control system with the engine-management system, brake system, transmission and cockpit. Here, subsystems from the drivetrain, chassis and infotainment (interaction with the driver) domains are used to realize the new function with minimal cost.

The decision as to whether a function (e.g. ACC) is realized in a dedicated logic close to the sensor or in one of the existing, subscriber electronic control units has no bearing on the function itself.

4 Example of a functional structure for the vehicle motion domain



Rather, the decision is affected by non-functional requirements such as safety, availability, costs or resource availability. In addition to the functional requirements, these requirements mainly determine how the function is realized. The "how" is described by the architecture of the system. Different requirements result in different system architectures.

CARTRONIC® concept

With the CARTRONIC® architecture concept, all closed and open-loop control tasks in the vehicle have been structured in accordance with logical, functional viewpoints and modeled in the form of a functional architecture. Delimited functions (and their dependencies) that implement specific functional requirements have been represented by defined architectural elements. The functional structure, i.e. the structural description, represented a hierarchical decomposition of the subsystems down to manageable size. Interactions between elements of the functional structure have been described by communication relationships. Since the use of the architecture concept could have led to different functional structures, it was essential to reach agreement on the tasks and interfaces. It was necessary to choose interfaces that were based on physical variables and thus supported aspects such as reusability and interchangeability.

The motor vehicle system with all its open and closed-loop tasks was dismantled into subsystems that implement clearly defined tasks. These subsystems include the engine management, brake system, transmission control, ACC, lighting management, etc. Different levels of functional structure detail can be assigned to the system and subsystem levels (Fig. 5). It was therefore possible to create development frameworks for selected functional components and component groups on which to base implementation in the form of partial realization stages. This required a decoupled development process and the exploitation of synergies between subsystems. The development frameworks took into consideration the dependencies and interface contents within the individual domains and with the rest of the vehicle, as is the case with a networked system such as ACC, for example.

Bosch introduced this concept to the Autosar Initiative (Workpackage 10.x).

Software architecture

The independence of the functional structure, or architecture, from the later realization stage results in a decoupling of functionality and technology and thus forms the first stage of a model-based development process. The functional structure can be used on several occasions and expanded as the foundation for drafting system architectures. This architecture is characterized by architecture drivers (specific criteria of the architecture) that are essentially the product of nonfunctional requirements (e.g. costs, quality, reusability, relocatability).

Further precision of the development frameworks devised from the functional structure, and of their interfaces in particular, is required if it is to be possible to evaluate an electronic control unit for the relocatability of functions and the integration of software, which is a contribution of various participants in the project. While retaining the realization-independent information from the functional structure – such as an agreed torque interface – the frameworks are supplemented by realization-specific information such as data type, quantization, runtime properties or resource requirements.

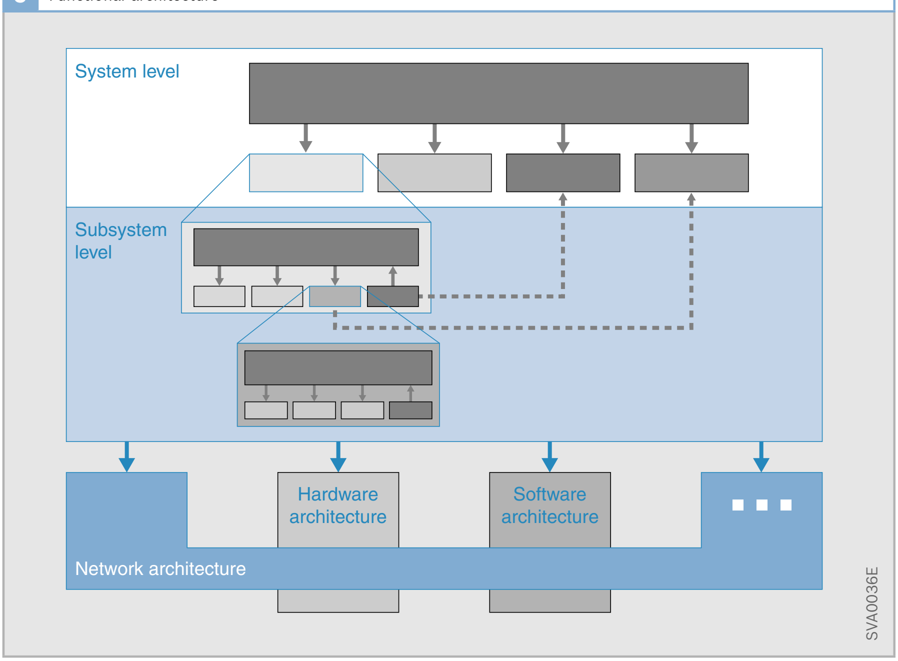
In the same way as hardware and disciplines such as mechanics or hydraulics, software can also be classified as a realization technology. Product-line or platform approaches have long been a familiar feature of mechanical development or production optimization and their application is virtually universal. The trend towards software-based system solutions and improvements, in conjunction with the vastly expanding software scopes of electronic systems, has given rise to the demand for this strategy to also be transferred to software-intensive systems.

The decisive challenge faced today is less to do with technical feasibility but more about how to develop methods further and apply already developed methods and processes in product developments in a systematic and disciplined way, and to anchor them within the organization. The product-line approach in software development was transferred to the motor vehicle domain with the participation of Bosch with methodological support from the software engineering institute (SEI). The method will be used systematically in future Bosch product generations.

Network architecture

With the spreading of open standards such as the CAN bus, the integration of functions into application-specific electronic control units, and satellites linked by subnetworks, network architecture has become the synonym for the complexity management of distributed systems. Extensions and “attachment solutions” are easily integrated until the limits of network capacity are reached. If these possibilities were to be exploited without checking the system draft, this would result in unmanageable increases in complexities and integration conflicts. Biological systems solve these unmanageable complexities through specialization and the creation of subnetworks with new forms of organization. Their objectives are stability and the ability to survive. This model has, to a certain extent, evolved on its own in motor vehicle systems through assignment to traditional

5 Functional architecture



fields of application or domains and the comparatively slow growth of networking within these domains.

Bus systems for the individual domains are becoming more specialized due to their plainly different requirements. With the CAN in the drivetrain as the point of origin, new bus systems such as the LIN subbus have begun to infiltrate the area of body electronics or FlexRay in the case of safety-relevant x-by-wire systems. In the multimedia field, where demands for high data rates but low safety requirements prevail, bus systems such as Bluetooth have started to make an appearance.

Breaking through these traditional domains with ever more applications leads to known consequences, e.g. dramatic increase in complexity, high start-up costs, increasing integration times and costs, and more demanding work in customer service as a consequence of diagnostics no longer being manageable. A solution for these multidimensional optimization tasks has in the past been sought in the software field. In the case of technical systems in particular, the paradigm is still king, especially in software realizations, because the absence of physical boundaries supports unlimited growth.

Autosar Initiative

The Autosar Initiative (AUTomotive Open Systems ARchitecture) was founded in July 2003 by several vehicle manufacturers and suppliers – Bosch among them. Their global objective is the joint development of an open system architecture for future automotive applications. The aims of the partnership include the standardization of fundamental system functions (basic software) and function interfaces; they will replace the company-specific, individual solutions used to date. Model-based concepts and methods ought to reduce complexity in spite of an expanding range of functions. The demands for quality and reliability are fulfilled by the multiple use of proven standards. Autosar concerns itself with all vehicle domains.

Based on the uniform electronics platform, which primarily consists of standard software modules, each vehicle manufacturer is then free to build its own specific content. They enable integration into the electronics network. These software functions permit differentiation between the competition.

Not only does software have to conform to the Autosar standard. The electronic control units must be built in such a way that the Autosar software is able to run on them. The Autosar members are hoping that the new development methods yield such benefits as shorter development times and lower development costs.

Until now, it was often the case that dedicated electronic control units would be developed and fitted for new functions (e.g. electronic transmission control, antilock brake system, air conditioning). The number of electronic control units fitted in the vehicle grew continuously; today's generation of vehicles are equipped with between 20 and 80 electronic control units. In future vehicle generations, it is intended that all functions be covered by a network of 10 to 20 electronic control units. Some of these will function a little like main computers that will bundle the important function groups together. These include the drivetrain, suspension management system, body and interior and the multimedia/telematics domain. On data buses, sensors with integrated electronics output processed and verified signals, while the buses carry the relevant control commands to actuators with integrated triggering electronics.

In future, new functions will often be able to use the existing computer architecture up to its performance limit and will be widely realized in the form of a software add-on. This would therefore render unnecessary the additional electronic control unit that would have been required today. The system only needs to be supplemented by the sensors and actuators required.

Software will no longer be an inevitable component of hardware, but will increasingly become a stand-alone product. The first examples of business and collaborative models between supplier and manufacturer have already been put into practice at Bosch, e.g. in drivetrain management.

Examples
Individually-controlled drive components at each of the wheels with different wheel positions and wheel loads permit optimum use of tire force potential. This results in increased driving dynamics and safety while at the same time reducing consumption, wear and emissions. For this to be possible, all active elements in the drivetrain, suspension and steering must be networked.

One example of superordinate functions realized by networking is the ASIS (Active Shift Strategy) drive strategy for automatic transmissions in passenger cars. Based on the evaluation of various control elements (e.g. accelerator pedal) and conclusions drawn from the information of other systems (e.g. cornering detection from the wheel speeds), this strategy is able to control the gearshift in such a way as to meet the driver's real-time demand for agility and power through selection of the appropriate gear. In future, the telematics will be able to support additional, improved driving strategies, e.g. through the use of GPS signals for transmission control in terms of predictive driving.

Outlook
Increasingly greater demands for safety, reliability and availability are being placed on the network architecture of modern vehicles. This is where energy network architecture will play a key role. In the face of vehicle functions increasingly being realized electronically, this architecture makes for a reliable supply of power to systems and thus forms the basis for the reliability and safety of future systems. One possible future technology is the transmission of power and information on the supply line. The following benefits arise from the powerline communication (PLC) concept used in the public grid:

- Weight and cost reductions as well as space savings from the discontinuation of data lines
- Easier retrofitting for retrofit systems (spare parts trade)
- Reduction in complexity of the wiring harness in respect of manufacture and installation
- Increase in system safety, especially in mechanically stressed zones (e.g. door, mirror) that are characterized by premature aging of lines and increased risk of failure
- Powerline as a redundancy path for systems relevant to safety
- Simultaneous, or parallel, implementation of several bus systems or services, e.g. diagnostics

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