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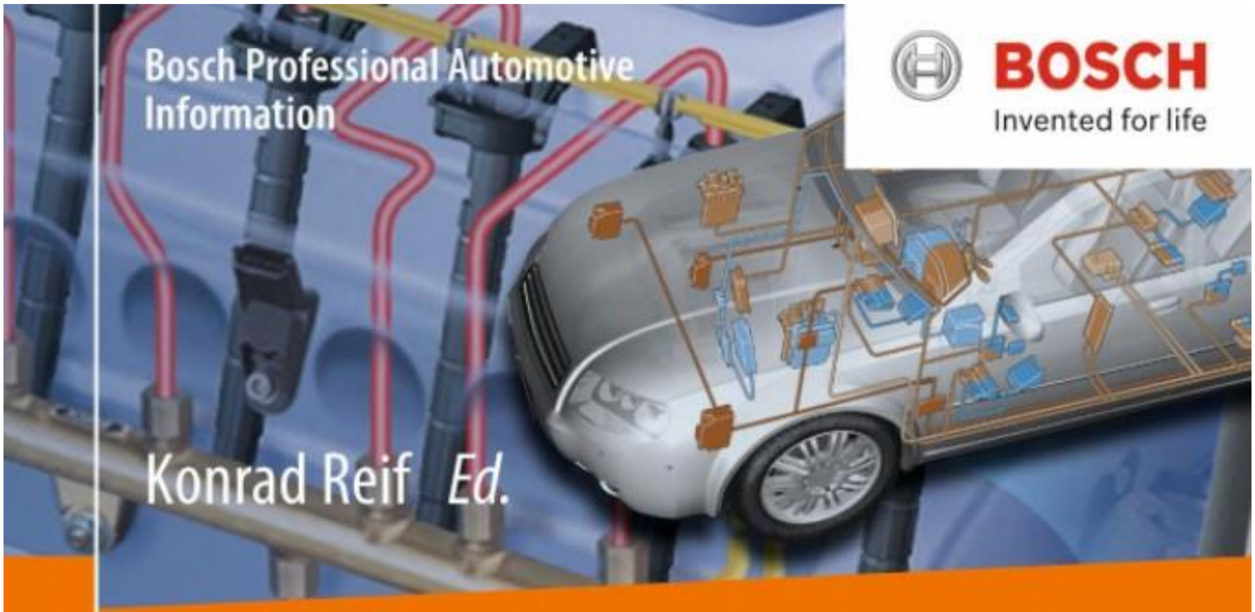


Konrad Reif Ed.

Automotive Mechatronics

Automotive Networking · Driving Stability Systems · Electronics

Basics of mechatronics

The term "mechatronics" came about as a made-up word from mechanics and electronics, where electronics means "hardware" and "software", and mechanics is the generic term for the disciplines of "mechanical engineering" and "hydraulics". It is not a question of replacing mechanical engineering by "electronification", but of a synergistic approach and design methodology. The aim is to achieve a synergistic optimization of mechanical engineering, electronic hardware and software in order to project more functions at lower cost, less weight and installation space, and better quality. The successful use of mechatronics in a problem solution is dependent upon an overall examination of disciplines that were previously kept separate.

Mechatronic systems and components

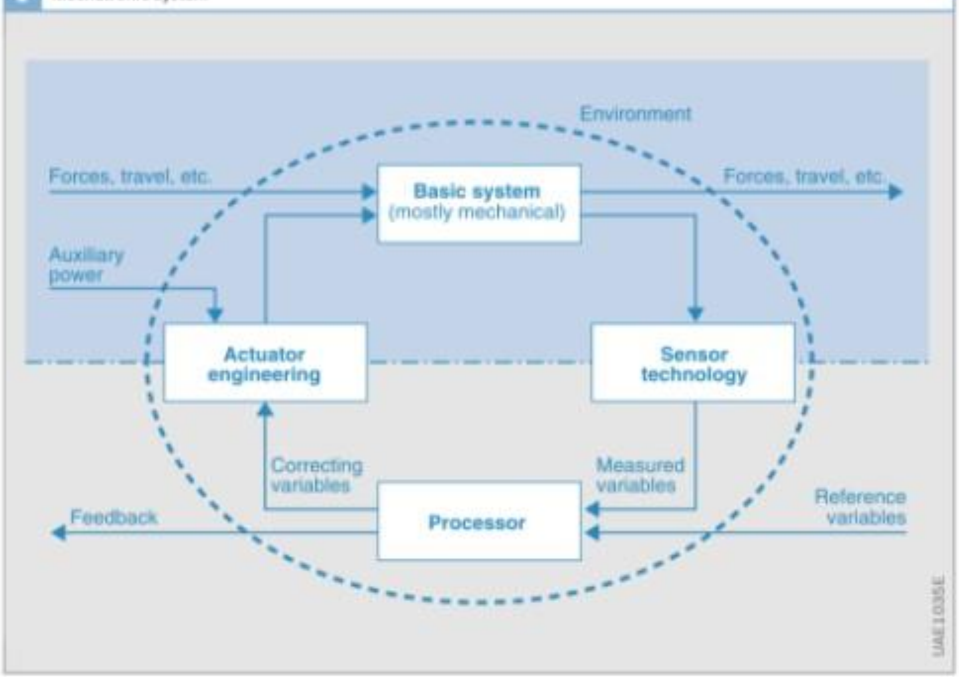
Applications

Mechatronic systems and components are now present throughout almost the entire vehicle: starting with engine-management systems and injection systems for gasoline and diesel engines to transmission control systems, electrical and thermal energy management systems, through to a wide variety of brake and driving dynamics systems. It even includes communication and information systems, with many different requirements when it comes to operability. Besides systems and components, mechatronics are also playing an increasingly vital role in the field of micromechanics.

Examples at system level

A general trend is emerging in the further development of systems for fully automatic vehicle handling and steering: more and more mechanical systems will be replaced by "X-by-wire" systems in future.

1 Mechatronic system



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DOI 10.1007/978-3-658-03975-2_1, © Springer Fachmedien Wiesbaden 2015

A system that was implemented long ago is the "Drive-by-wire" system, i.e. electronic throttle control.

"Brake-by-wire" replaces the hydromechanical connection between the brake pedal and the wheel brake. Sensors record the driver's braking request and transmit this information to an electronic control unit. The unit then generates the required braking effect at the wheels by means of actuators.

One implementation option for "Brake-by-wire" is the electrohydraulic brake (SBC, Sensotronic Brake Control). When the brake is operated or in the event of brake stabilization intervention by the electronic stability program (ESP), the SBC electronic control unit calculates the required brake pressure setpoints at the individual wheels. Since the unit calculates the required braking pressures separately for each wheel and collects the actual values separately, it can also regulate the brake pressure to each wheel via the wheel-pressure modulators. The four pressure modulators each consist of an inlet and an outlet valve controlled by electronic output stages which together produce a finely metered pressure regulation.

Pressure generation and injection are decoupled in the Common Rail System. A high-pressure rail, i.e. the common rail, serves as a high-pressure accumulator, constantly providing the fuel pressure required for each of the engine's operating states. A solenoid-controlled injector with a built-in injection nozzle injects fuel directly into the combustion chamber for each cylinder. The engine electronics request data on accelerator pedal position, rotational speed, operating temperature, fresh-air intake flow, and rail pressure in order to optimize the control of fuel metering as a function of the operating conditions.

Examples at component level

Fuel injectors are crucial components in determining the future potential of Diesel-engine technology. Common-rail injectors are an excellent example of the fact that an extremely high degree of functionality and, ultimately, customer utility can only be achieved by controlling all the physical domains (electrodynamics, mechanical engineering, fluid dynamics) to which these components are subjected.

In-vehicle CD drives are exposed to particularly tough conditions. Apart from wide temperature ranges, they must in particular withstand vibrations that have a critical impact on such precision-engineered systems.

In order to keep vehicle vibration away from the actual player during mobile deployment, the drives normally have a spring damping system. Considerations about reducing the weight and installation space of CD drives immediately raise questions concerning these spring-damper systems. In CD drives without a damper system, the emphasis is on designing a mechanical system with zero clearances and producing additional reinforcement for the focus and tracking controllers at high frequencies.

Only by combining both measures mechatronically is it possible to achieve good vibration resistance in driving mode. As well as reducing the weight by approx. 15 %, the overall height is also reduced by approx. 20 %.

The new mechatronic system for electrically operated refrigerant motors is based on brushless, electronically commutated DC motors (BLDC's). Initially, they are more expensive (motor with electronics) than previous DC motors equipped with brushes. However, the overall optimization approach brings benefits: BLDC motors can be used as "wet rotors" with a much simpler design. The number of separate parts is therefore reduced by approx. 60 %.

In terms of comparable cost, this more robust design doubles the service life, reduces the weight by almost half and reduces the overall length by approx. 40 %.

Examples in the field of micromechanics

Another application for mechatronics is the area of micromechanical sensor systems, with noteworthy examples such as hot-film air-mass meters and yaw-rate sensors.

Because the subsystems are so closely coupled, microsystems design also requires an interdisciplinary procedure that takes the individual disciplines of mechanical components, electrostatics and possibly fluid dynamics and electronics into consideration.

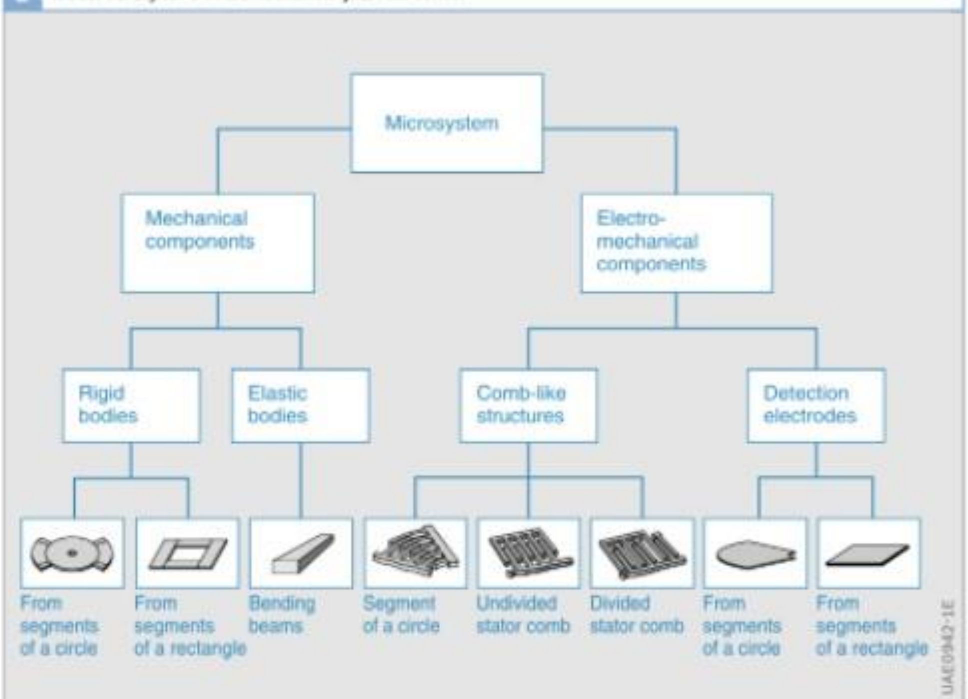
Development methods

Simulation

The special challenges that designers face when developing mechatronic systems are the ever shorter development times and the increasing complexity of the systems. At the same time, it is vital to ensure that the developments will result in useful products.

Complex mechatronic systems consist of a large number of components from different physical domains: hydraulic components, mechanical components and electronic components. The interaction between these domains is a decisive factor governing the function and performance of the overall system. Simulation models are required to review key design decisions, especially in the early development stages when there is no prototype available.

2 Model library for a micromechanical yaw-rate sensor



V model

The dependencies of the different product development phases are illustrated in the "V model": from requirement analysis to development, implementation, testing and system deployment. A project passes through three "top-down" levels during the development stage:

- Customer-specific functions
- Systems and
- Components

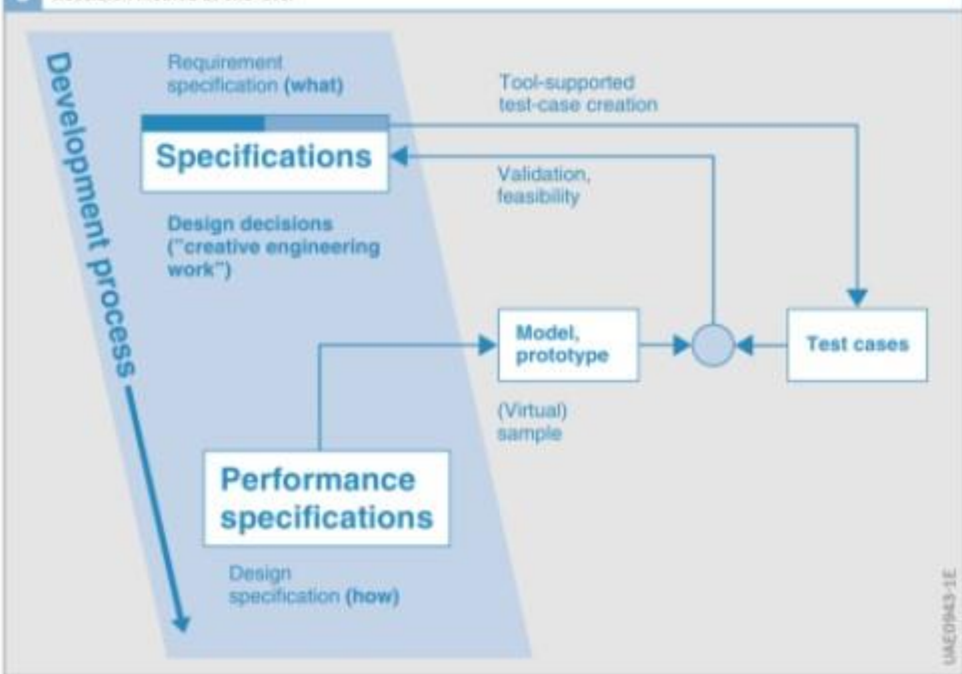
A requirements specification (what) must first be produced at each level in the form of specifications. This results in the design specification, which is drawn up on the basis of design decisions (the actual creative engineering work). The performance specifications describe how a requirement can be met. The performance specs form the basis for a model description which allows a review (i.e. validation) of the correctness of each design stage together with previously defined test cases. This procedure passes through each of three stages, and, depending on the technologies applied, for each of the associated domains (mechanical engineering, hydraulics, fluid dynamics, electrics, electronics, and software).

Recursions at each of the design levels shorten the development stages significantly. Simulations, rapid prototyping, and simultaneous engineering are tools that allow rapid verification, and they create the conditions for shortening product cycles.

Outlook

The major driving force behind mechatronics is continuous progress in the field of microelectronics. Mechatronics benefits from computer technology in the form of ever more powerful integrated computers in standard applications. Accordingly, there is a huge potential for further increases in safety and convenience in motor vehicles, accompanied by further reductions in exhaust emissions and fuel consumption. On the other hand, new

3 Recursion method at one level



challenges are emerging with regard to the technical mastery of these systems.

However, future "X-by-wire" systems without the mechanical/hydraulic fallback level must also provide the prescribed functionality in the event of a problem. The condition for their implementation is a high-reliability and high-availability mechatronic architecture which requires a "simple" proof of safety. This affects both single components as well as energy and signal transmissions.

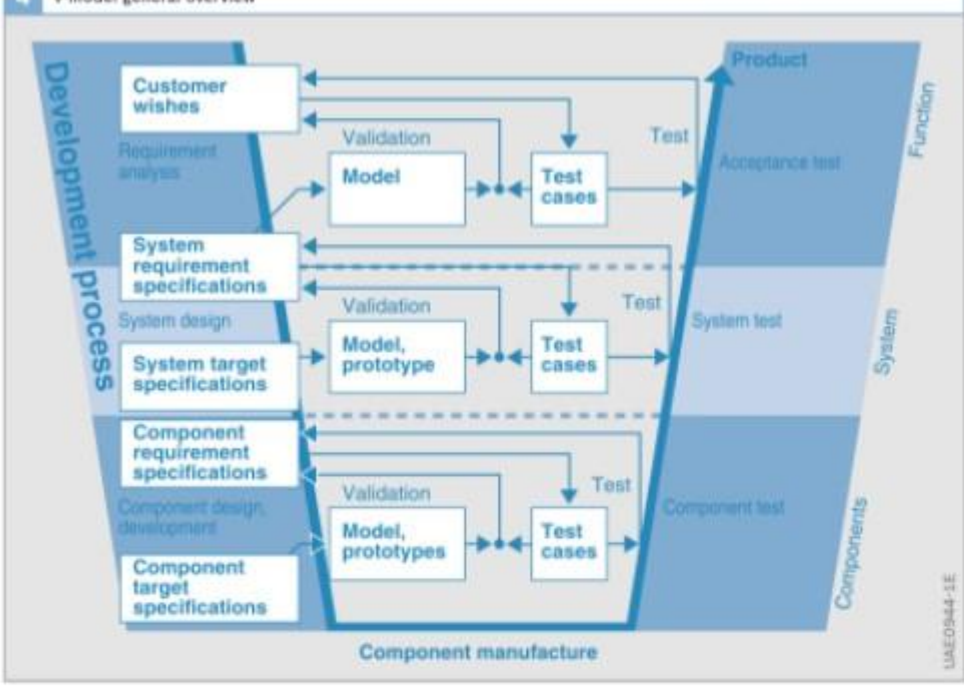
As well as "X-by-wire" systems, driver-assistance systems and the associated man/machine interfaces represent another area in which the consistent implementation of mechatronic systems could achieve significant progress for both users and vehicle manufacturers.

The design approaches of mechatronic systems should strive toward continuity in several aspects:

- Vertical:
  "Top-down" from system simulation, with the objective of overall optimization, through to finite element simulation to achieve a detailed understanding, and "bottom-up" design engineering from component testing through to system testing
- Horizontal:
  "Simultaneous engineering" across several disciplines in order to deal with all product-related aspects at the same time
- Beyond company boundaries:
  Step by step, the idea a "virtual sample" is nearing our grasp

Another challenge is training in order to further an interdisciplinary mindset and develop suitable SE processes and forms of organization and communication.

4 V-model general overview



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

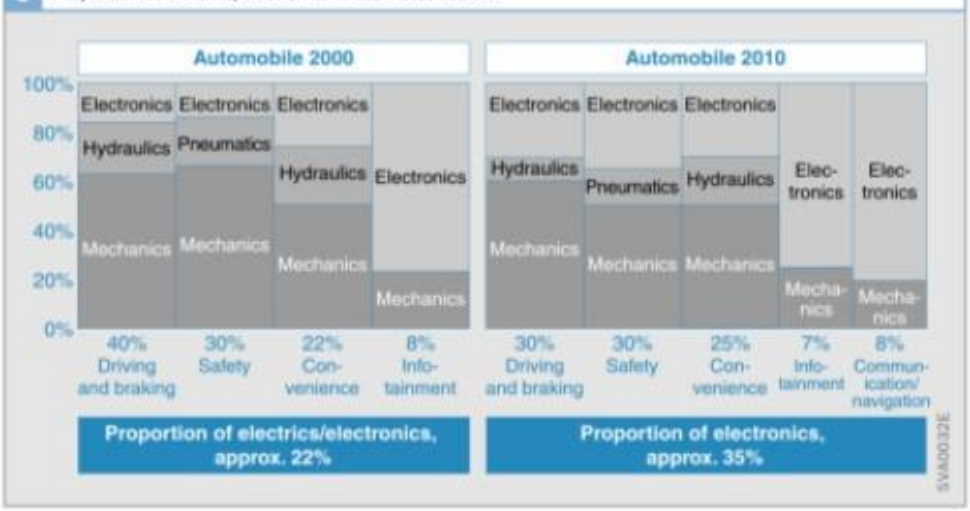
History

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



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Technology of the present day

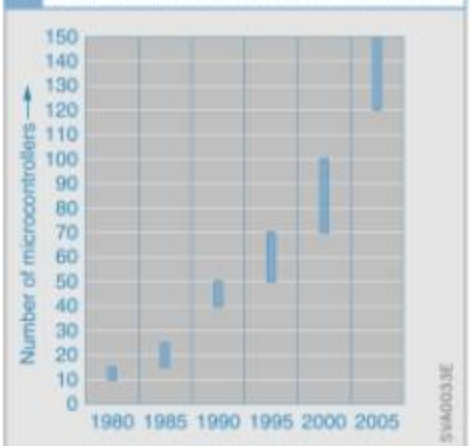
In the 1990s the cabling work in a luxury class vehicle amounted to around 3 km. This figure clearly demonstrates how complex the vehicle system has become. The growth of the proportion of electronics in the motor vehicle (Fig. 1) can mainly be attributed to the growth in microelectronics and sensor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