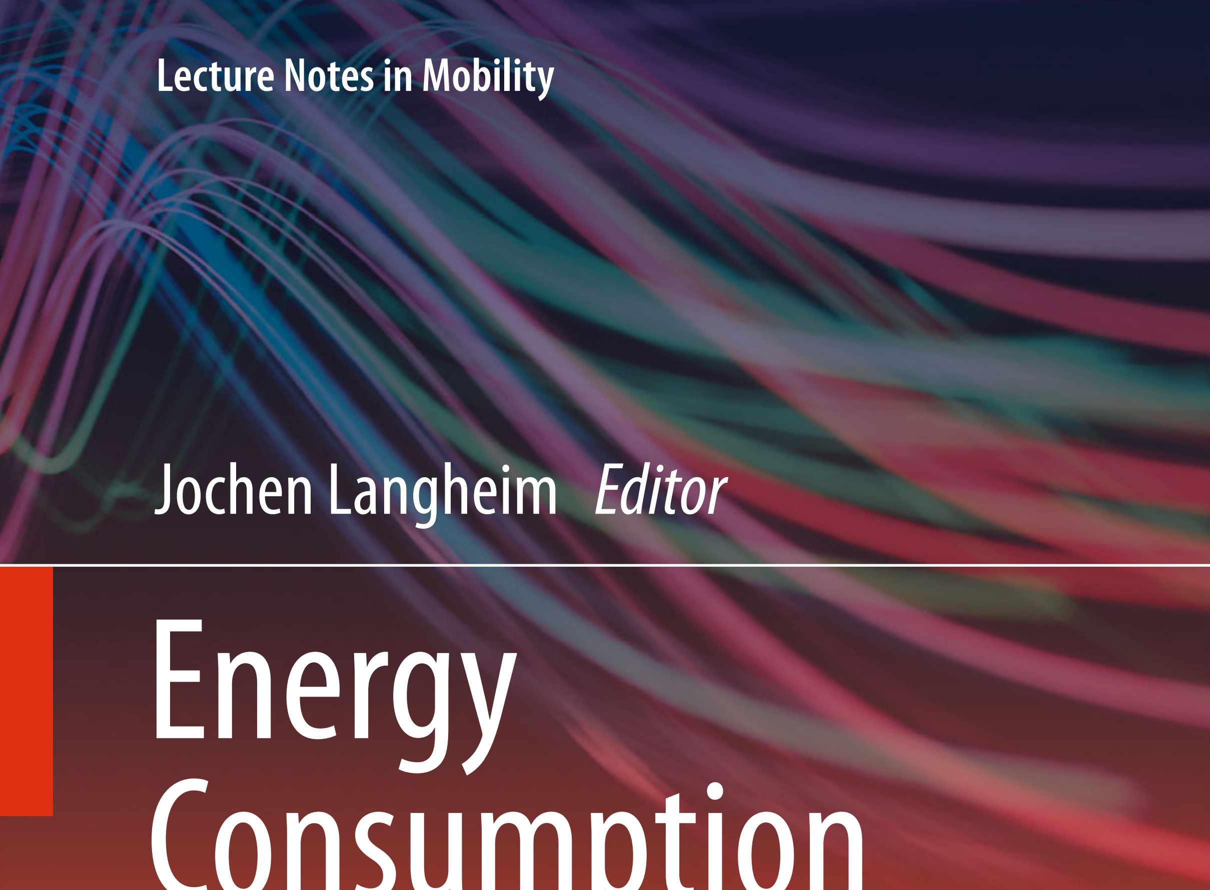

Lecture Notes in Mobility

Jochen Langheim *Editor*

Energy Consumption and Autonomous Driving

Proceedings of the 3rd CESA Automotive Electronics Congress, Paris, 2014

Springer

Lecture Notes in Mobility

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Preface

Innovation drives industry, keeps it competitive, generates business, and valuable employment. In the automotive industry, innovation is key to survival. And for the automobile world, innovation means … electronics.

Electronics is reinventing the car. The good old mechanics, the powertrain is turning to hybrid, not to say pure electric. The usage of the car is now connected with any electronic mobile device and to the main data centers and sometimes … without driver.

The share of electronics in the total value of passenger cars has been rising from 20 to almost 40 % in 10 years. This leads to the headline in the newspapers: restructuring, because traditional industry has gone down from 80 to 60 %. Restructuring is key in almost all traditional branches of car industry.

CESA was created in 2009 as car industry met the biggest crisis for decades. At this moment, electronics stepped strongly out of the shadow of the different domains. It became very clear that electronics is bringing fresh air with more and more appealing products and is today an essential driver for innovation and thus employment in this important sector of Europe's industry.

A fundamental revolution has already taken place. And we even see electronic engineers becoming presidents of car manufacturers today. This was unthinkable some years ago.

And further revolutions are on their way.

Keywords are

ADAS towards autonomous driving

Connected cars for safety and efficient mobility

Connected cars linked to Internet of things for keeping the customer on line

Advanced HMI to help all the different customers to use safely and easily these new ways of mobility

Electrification of the powertrains toward smart grids and smart cities

Cars are moving in a complex environment, while respecting increasingly stringent air quality and safety standards with being safe meaning the reduction of the risk of accidents, being compatible with many different regional legal requirements and infrastructures, being comfortable and affordable.

More than ever, worldwide business relations and global market developments determine the health of the automotive industry. Europe is still a leader in many technical areas, but there are decisions on road safety or environment protection taken somewhere in the world that affect the global system and our markets. Asia is eager to catch up and the Silicon Valley is now targeting automotive applications as well.

The breakthrough of driver assistance systems is here. Automatic parking, emergency braking, or pedestrian protection systems are proliferating in all car segments and sales numbers are increasing rapidly. CESA did look at the new technologies that address increasing levels of driving automation and asked the question, what would be the consequence of a world of automation of driving in terms of infrastructure and usage of the cars of tomorrow. Several users might want to get their cars back at the parking at the same time. If not coordinated, this will create new kinds of traffic jams. Therefore, we do not only need onboard electronics, but also an intelligent and adapted infrastructure.

In this world of Internet of Things, the car is rapidly becoming one of the main connected elements in our daily life. This requires technical solutions that are not all yet known; many challenges and opportunities have arisen recently. Let us just think of the arrival of the iPhone in 2007. So many new services that nobody, but perhaps Steve Jobs, could imagine.

The society is overwhelmed, habits and values have changed almost too fast. Conscience is following slowly, but now more and more users are asking themselves the question, if they really wish to give access to their most intimate data. This requires answers that CESA did address in this edition.

Road transport is undergoing major technological changes with the communication technology car2X and progressive vehicle automation. These technological developments will lead to a paradigm shift in the way drivers should interact with their vehicle. The definition of future vehicle Human–Machine Interfaces (HMI) will intensify the need to involve further competences including cognitive ergonomists, psychologists, and interaction designers to be able to manage this new complexity and the interaction between human and robots.

The “driver” will need to understand what the car is doing during autonomous driving phase, be confident but also vigilant. As a side effect, entertainment proposed during autonomous driving will be completely different from the existing one in traditional cars. Moreover, there exists the critical phase, when the passenger has to take back his responsibility and take over the driving activity. This requests particular caution and careful design to allow a save takeover.

This clearly means that cockpit design will progressively change from a driving task-centered design to an autonomous driving-centered design. HMI will be a key enabler for complexity management.

Standardization will help to develop the market faster and make sure that the different levels of automation are understood and accepted rapidly. On one hand, the driver shall be discharged and on the other hand he needs to stay in the decision and handle difficult situations. Consequently, the transition between automatic driving and normal driving, the takeover to normal driving requires particular care.

The increase in the number of functions forces to manage carefully the complexity and the combination of the variants which have to be tested. In the upcoming years, testing will remain an unabated core theme, since the final result is a product that goes into production. The business challenge lies in the right mix of intense testing of new developments with human control in the loop and virtual validation as much as possible to keep development complexity reasonable and product liability clear.

Nothing is written in advance in that matter; we all need to team up to better fulfill the end users' needs offering a real standardization … while keeping up brand differentiation!

As in the previous editions, energy consumption was also a topic in Paris this year. New trends and new regulations lead to green cars with technological changes for internal combustion engines, hybridisation and electrification.

Finally, CESA did also look into new technologies in the fields of semiconductors, connection materials, cables, packaging, and plastics that continuously penetrate electronics domains.

Some are still in the state of advanced research, others are already used in industrial, aeronautic, or consumer applications and not always considered by the automotive industry yet. What are such new technologies? What can they bring? Can they easily be applied in automotive electronics applications, and what is needed to get the maximum benefit out of them?

This edition is a collection of some contributions to this CESA edition. The authors have agreed to share their experience and knowledge with the public in this form and we hope that it gives the reader a good overview of the issues that have been discussed.

It cannot be said enough, but without the outstanding level of motivation and the large number of constructive contributions of the committee members, CESA could never succeed.

Exchange and communication is essential to accompany this revolution in the long run. CESA 3.0 was only one event in a long row of many events, in which CESA is the most general. It is today a recognized and established date in the agenda of automotive industry managers and we invite you already to follow the next edition in 2016 end.

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Contents

Part I Market

Part II Connected Car and Acceptance

Part III Technical Progress—ADAS

Part IV New Usage of Cars with More Automation

Part V Standards, Test, Validation

Part VI CO_2 Reduction, Hybridization, Regulation

Part VII Key Technologies for Modern Cars

Part VIII Human Factors in Modern Cars

Part IX Keynote of FIEEC to CESA 3.0 Congress on Automotive Electronic Systems

Part I

Market

Autonomous Driving: Disruptive Innovation that Promises to Change the Automotive Industry as We Know It

Wolfgang Bernhart and Marc Winterhoff

Abstract Among the trends that are going to shape the automotive industry in the coming years, autonomous driving stands out as having the potential to completely change the automotive industry as we know it. While analysts may still debate the pace of change, the current state of autonomous driving technology or the power dynamics between incumbents and new entrants, there is no longer a debate over if autonomous driving is going to happen, but when. For traditional players in the automotive industry, this means they have a series of strategic questions to answer that will determine the path to the autonomous driving future and their roles in it. This paper is an excerpt of a Roland Berger Strategy Consultants study recently published on the topic [1].

1 Automated Driving: A Staged Evolution

1.1 A Combination of Technology Innovation, Competitive Forces, Benefits and Regulations Are Fueling the Trend Towards Automated Driving

Today, there are five key factors that are influencing the evolution of autonomous driving.

Technological innovation: Major automotive companies and technology companies have already demonstrated autonomous driving through working prototypes and pilots, with automated driving also being one of the main themes at the 2015

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CES in Las Vegas. Several advanced driver assistance systems (ADAS) such as active lane keep assist, adaptive cruise control and self-parking are already available as combined functions on current generation cars. Additional functionality is expected to be rolled out in the next few years. Furthermore, significant efforts are being made to advance existing technology and to address cost-side challenges. Therefore, both the availability and affordability of key technologies to enable autonomous driving is expected to greatly increase in the coming years.

Competitive forces: The entire automotive industry is aware of the potentially huge market emerging from autonomous driving.

Individual consumer benefits: Several studies highlight the commute burden that people face today. The total time people spend driving cars per year is in the same amount people using the internet.

Societal benefits: Autonomous driving could provide three major transportation related benefits to society—decreased traffic congestion, improved road safety and reduced carbon emissions.

Regulation: Regulatory bodies across the globe are starting to pave the way for autonomous vehicles by developing the appropriate legal framework for vehicle testing and operation. In the US, where state legislation governs autonomous vehicles, Nevada, California, Florida and Michigan have already passed laws legalizing autonomous driving for various usage applications and conditions. In Europe and other countries that have signed the Vienna convention on road traffic, legislation is being altered in favor of promoting autonomous vehicle development. However, there are still a lot of open questions to be solved, if European countries want to play a leading role in the development.

In Japan, the government started granting auto manufacturers special permission to test autonomous vehicles on public roads since 2013. In addition, the Japanese government is actively promoting R&D of autonomous driving technology through its Strategic Innovation Promotion (SIP) program in collaboration with various ministries, experts from academia, government agencies and industries.

1.2 A Staged Evolution: Early Autonomous Driving Features Are Already Available, While Full Self-Driving Automation Will Be Ready by 2025–2030

While the advent of autonomous driving is certain, we expect a staged introduction of autonomous driving functionality over the next 15 years. Today, many vehicles on the road are equipped through “Level 1: function-specific automation” with features such as cruise control and automatic braking. Advanced driver assistance features (such as adaptive cruise control combined with lane keep assist), referred to as “Level 2: combined function automation”, are already offered by many established manufacturers.

Looking forward, we project “Level 3: limited self-driving automation” to be available by 2018–2020 with features such as highway chauffeur (automated driving on highways). Furthermore, we expect “Level 4: full self-driving automation” to be first offered for low speed situations by 2020–2025 (e.g., in parking lots or low-speed areas) and eventually, including more complex operations to be offered by 2025–2030 (e.g., city driving). Even with the introduction of new technologies, we do not expect global adoption of full self-driving automation with “door-to-door” capabilities across all vehicle segments before 2030–2040.

2 Technology to Replace Human Senses: Removing the Human from the Driver’s Seat Requires Four Key Areas of Mastery

The lack of a human element in driving activity requires critical sensory functions to be performed using various technologies simultaneously, Fig. 1.

Many of these technologies already exist today. However, facilitating even “Level 3” functionality of highly automated driving/limited self-driving in complex traffic and driving conditions requires mastery in several areas:

1. **Vehicle’s location and environment**: As there would no longer be active human input for vehicle functions, highly precise and real-time information of a vehicle’s location and its surrounding environment will be required (e.g., road signs, pedestrian traffic, curbs, obstacles, traffic rules).

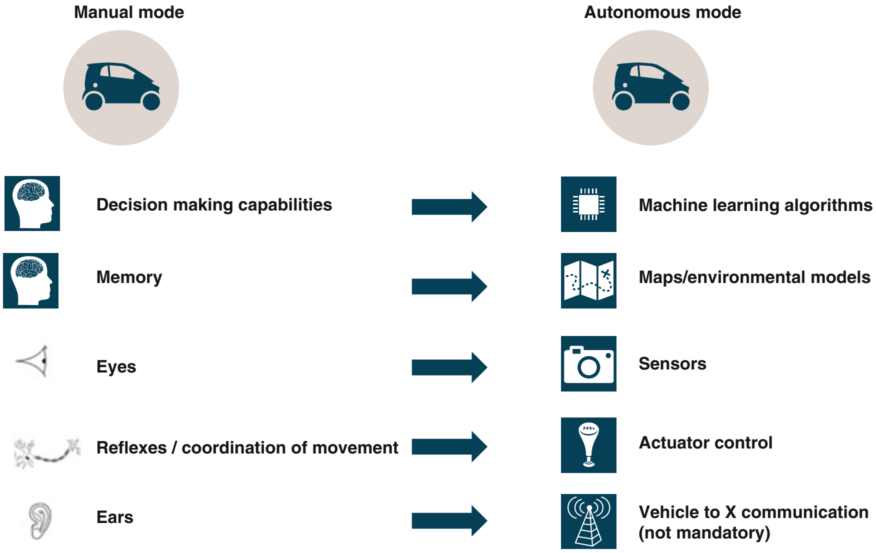

Fig. 1 Replacing sensory functions with technology

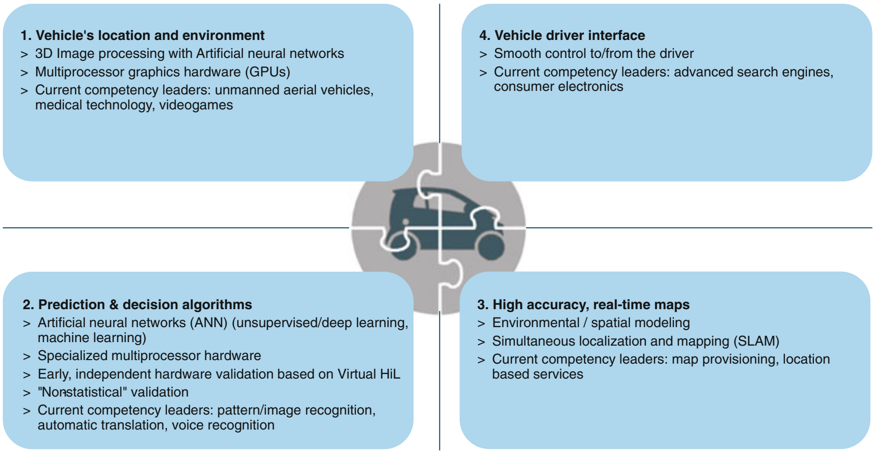

Fig. 2 Required areas of mastery for fully automated driving

2. **Prediction and decision algorithms**: Advanced concepts based on Artificial Neural Networks (unsupervised/deep learning, machine learning) will be needed to create systems to detect, predict and react to the behavior of other road users, including other vehicles, pedestrians and animals.
3. **High accuracy, real-time, learning maps**: Detailed and complete maps must be available to provide additional and redundant information for the environmental models that vehicles will use for path and trajectory planning.
4. **Vehicle driver interface**: A self-adapting interface with smooth transition of control to/from the driver, mechanisms to keep the driver alert and a flawless ride experience (with a vehicle performing as expected) will be instrumental in winning consumer confidence (Fig. 2).

3 Significant Opportunities Await: By 2030, New Opportunities from Autonomous Driving Will Be Around USD 40–60 bn, and That's just the Start

On the journey to mass adoption of full self-driving automation, we will see an evolutionary change in the automotive industry with several key implications.

Hardware components: The market for autonomous driving hardware components, such as cameras, sensors, communication systems, will—with the exception of "intelligent" cameras—most likely remain with automotive manufacturers and a core group of Tier 1 suppliers. By 2030, we estimate the entire market for new components to be around USD 30–40 bn, Fig. 3.

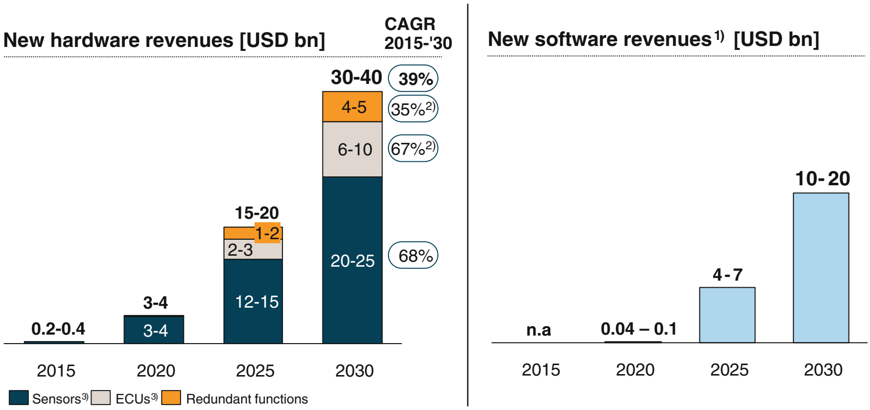

Fig. 3 Estimated additional revenues from highly and fully automated driving systems (on-board systems only). *1* Prediction and decision algorithms; *2* 2020–2030; *3* Excludes cost of current ADAS sensor and ECU package, some of which will be made redundant by e.g. installation of a central master ECU

High accuracy mapping and prediction and decision algorithms: Two of the most critical elements of automated driving technology include new areas such as high accuracy mapping and prediction and decision algorithms. Both of these areas are mainly software-based and require large upfront investments in capital and time for development. Several major technology players already have a head start and therefore, are well positioned to lead the charge in these market spaces. By 2030, the market for this new software could reach USD 10–20 bn, depending on the business models applied, Fig. 3.

OEMs and full-scale system suppliers who are not yet active in high accuracy learning maps can still enter this space, but they have to make several key strategic decisions soon. Available options include making the upfront investments alone or establishing alliances with other OEMs or technology players—we have already seen development in this direction earlier this year.

To develop “decision making” systems for automated driving, strong capabilities in the latest applications of Artificial Neural Networks (ANN) will be required. OEMs or full-system suppliers may choose to partner with research institutes or alternatively, form alliances with or acquire active players to quickly build the key competencies. The recently announced alliance between Nissan and NASA is one of those examples. OEMs and suppliers must act fast as this area is receiving increasing attention from other industries as well.

Monetization models: Young and technology-savvy consumers are most likely to adopt autonomous driving technology early. However, for the mass market segment, the additional USD 3,000–6,000 currently charged by premium OEMs for advanced driver assistance systems may create a barrier for adoption. OEMs may need to rethink the business models for monetization of automated driving technology to foster quick adoption of autonomous driving. Suppliers also need to carefully evaluate technology priorities in order to focus on those technologies that can be monetized first.

4 Fortune Favors the Prepared: To Capitalize on the New Opportunities, OEMs and Suppliers Need to Prepare and Take Action Today

4.1 Key Focus Areas for OEM

With new players from technology and IT sectors entering, OEMs need to step up efforts to defend their position in the automotive value chain.

4.1.1 Driving Experience

For more than a century, automotive manufacturers have mastered the overall driving experience, and they should continue to leverage this to their advantage. Even in the age of automated driving, the ride experience and vehicle control will remain very important to demonstrate comfort and safety. Furthermore, the vehicle's ability to adapt to driver expectations will be crucial for winning consumer confidence and acceptance.

4.1.2 Prediction and Decision Algorithms

Considering the scale of investments required in the area of prediction algorithms, large and premium OEMs are best positioned to pursue building the required capabilities. OEMs should prepare and execute a strategy for developing prediction algorithms based on their respective sizes, access to resources and expanding core capabilities. To support these efforts, OEMs can leverage data from vehicles already on the road. Another important consideration is that OEMs should defend their position against new technology players who try to enter the market, through controlled access to vehicles and customers.

4.1.3 Architecture

In order to choose the best suppliers for specific functions and to help system elements keep up with the quick pace of innovation (e.g., decision algorithms, electronics), OEMs should establish their own proprietary standards and central architectures with clear interfaces. This would allow for the independent separation of specific functional areas, which will become important for design validation and verification, an area expected to be a major—if not the largest—cost component in the overall development of automated systems. Also, decoupling of hardware and software might allow for independent validation activities for control algorithms and derived hardware requirements, thus reducing time and costs significantly. For example, OEMs could evaluate processing times of old vs. new hardware generations in simulated environments (Virtual HiL-type).

4.1.4 Business Models

OEMs need to consider adopting new business models to address the inherent affordability challenge for early adopters, to quickly increase the base of autonomous vehicle users and to maximize value captured. Lessons for new business models can be learned from other industries—examples include providing low upfront system prices for customers while OEMs leverage the data, offering pay-per-use mobility services or bundling autonomous driving features with other connected services.

4.1.5 Areas of Differentiation

Finally, automotive manufacturers have to rethink areas of differentiation. Once full self-driving automation is established, and as humans no longer partake in the driving activity at this stage, driving dynamics will be less differentiating and hence will become less important. On the other hand, the commute time is now freed up to pursue other activities such as entertainment, work or rest. Therefore, ride and interior comfort along with productivity/entertainment features would gain utmost importance.

Meanwhile, the ability of the vehicle to adopt and behave according to the expectations of specific users, the range of potential traffic situations covered (and therefore the ability to drive safely faster than other vehicles in automated mode), and the possibility to upgrade cars already in use are likely to become important differentiation areas for the next 10–20 years.

4.2 Key Focus Areas by Supplier Type

As the industry moves towards a more centralized architecture and automated driving functionality, a central electronic control unit (ECU) could replace multiple function-specific ECUs currently used for ADAS. As discussed, OEMs could try to build a core system with separate system elements to cherry pick the best solutions and to take advantage of the fast pace of other players' innovations. Considering these changes, suppliers need to act depending on their competencies in the autonomous driving space.

4.2.1 Major System Suppliers Providing Full–Spectrum Solutions

Suppliers in this category should look to make major investments in prediction and decision algorithm technologies, including machine learning, and to actively screen specialists/start-ups with strong experience in “deep learning” capabilities as acquisition targets or strategic partners. This will allow these suppliers to participate and remain relevant for autonomous vehicles by offering innovative, complete solutions to smaller OEMs and by delivering highly safety critical systems (ASIL D level safety). Early cooperation with these smaller OEMs might also give suppliers access to real on-road data to further advance the respective algorithms/ANNs.

To prevent OEMs’ push towards value chain decomposition, suppliers can emphasize liability issues that affect industry dynamics, while simultaneously working on their own architectural standards. However, given the huge investments required in the sector, we do not see room for more than three or four major global players in the long run.

4.2.2 Specialized Suppliers Already Active in Areas of ADAS and Active Safety

Suppliers of single assistance systems will face tremendous pressure from ongoing trends, such as the centralization of ECU architecture, as well as from new entrants, e.g. from the Aerospace/Defense area of semiconductor manufacturers expanding their business downstream. Therefore, instead of focusing on functional innovation only, these suppliers should focus aggressively on cost and cater to the volume/budget segments of the market.

4.2.3 Suppliers Focused on Technology Innovation

These players will need to focus on their technology, while simultaneously making required investments to attain a global top-3 position in their respective domains. This is the only way that they can ensure their positioning as technology leaders and also as Tier 1 suppliers. Examples of opportunities include greater functional integration of actuators to reduce cost, or on the camera side, a push towards low-cost hardware supported by Artificial Neural Network technology.

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Part II
Connected Car and Acceptance

Automotive Security Testing—The Digital Crash Test

Stephanie Bayer, Thomas Enderle, Dennis-Kengo Oka and Marko Wolf

Abstract Modern vehicles consist of many interconnected, software-based IT components which are tested very carefully for correct functional behavior to avoid safety problems, e.g. the brakes suddenly stop working. However, in contrast to safety testing systematic testing against potential security gaps is not yet a common procedure within the automotive domain. This however could eventually enable a malicious entity to be able to attack a safety-critical IT component or even the whole vehicle. Several real-world demonstrations have already shown that this risk is not only academic theory [1]. Facing this challenge, the paper at hand will first introduce some potential automotive security attacks and some important automotive security threats. It then explains in more detail how to identify and evaluate potential security threats for automotive IT components based on theoretical security analyses and practical security testing.

Keywords Automotive security analysis · Automotive security testing · Automotive penetration testing

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1 Introduction

Suddenly car drivers all over the world witness spooky behavior of their Internet-enabled car infotainment units over the past few days. Out of the blue their navigation system jumps to another route, the unit calls service numbers on its own, or the display shows sculls and laughing, white masks. A quick analysis by security experts shows that the reason behind this behavior is a critical security breach of the Internet-enabled GSM/LTE interface that enables unauthorized persons to access the software of the vehicle infotainment unit. But, how is it possible that this vulnerability had been missed, as the infotainment unit passed numerous tests before going into series production? The answer is quite simple; even though there were several tests focusing on the functionality and safety, a systematic security evaluation containing theoretical analysis and practical tests had not been accomplished.

Luckily, this is only a potential scenario (yet) and not a real case but the above scenario clearly exposes a critical gap in automotive IT testing, which is not yet covered by existing functional testing procedures that are already well-established and have been conducted for several decades. However, in contrast to functional testing, the systematic evaluation of automotive IT components regarding their IT security is still in a very early stage. At the same time there is a strong need for security testing as a part of the automotive engineering procedure, not only due to scenarios like the introductive example but also as a result of corresponding automotive IT security research activities [2, 3], and increasing demands made by public authorities [4].

The paper is structured as follows. First we discuss recent automotive IT security threats ranging from odometer manipulations up to remote controlling of the steering system. Then, we give an overview and a short introduction to the different aspects of automotive security evaluations. We discuss theoretical security analyses and explain practical security testing, especially regarding automotive onboard IT components.

2 Automotive Attack Motivations and Threats

This section presents an overview of potential automotive security threats. To understand the types of threats, one must first have a basic understanding of various automotive functionalities which can be targeted. Obviously there are direct security threats on driving safety such as manipulating the steering wheel or brakes, and indirect security threats such as distracting the driver by triggering odd vehicle behavior. Security researchers have successfully demonstrated that it is already possible to engage or disable the brakes or manipulate the steering wheel [1–3, 5] by maliciously injecting the relevant messages on the vehicle CAN bus. Indirect safety issues are possible by injecting CAN messages to, for example, disable wipers or turning off the headlights when it is raining and dark outside.

Another type of security threat is targeting authoritative functionalities in the vehicle. For instance, the odometer logs the traveled distance and, when selling a used car, it is attractive for an attacker to reduce the value of the odometer to increase the value of the car. In Germany, according to police investigations, around 2 million cars are subject to odometer manipulation per year with an average loss per vehicle of around 3000 € resulting in total losses of around 6 billion € per year [6]. Furthermore, critical data are stored in the ECUs such as crash data, data for insurances, or warranty indicators. Such data are also very attractive for malicious manipulations. For example, data such as vehicle speed, seat belt status, brake pedal position etc. are typically recorded in the seconds before a crash. A driver who has been involved in an accident could be motivated to change the recorded data to indicate that the brakes were applied when they really were not.

Moreover, since vehicles are becoming ubiquitously interconnected, private data such as vehicle location, credentials to online services, or mobile payment data becomes increasingly stored in the vehicle as well. Attackers may be interested in stealing such data and misuse them directly or as a stepping stone to launch further attacks, for instance, attacking an online service by stealing the respective credentials stored in the vehicle. These private data could be extracted wirelessly by exploiting security vulnerabilities in services provided by communication interfaces such as Bluetooth and Wi-Fi or through physical access to the OBD port, a USB port or the ECU itself.

Another type of threat is theft of vehicles or valuable vehicle components such as airbags or head units, e.g. by abusing diagnostics commands to reprogram a new key. This functionality is typically used by workshop dealers when replacing a lost key, but can also be exploited by attackers to program a “thief key” for the vehicle that they are stealing [7]. There are other cases where attackers are able to send control messages to a vehicle to disable the alarm and unlock the doors, resulting in attackers being able to gain physical access to the interior of a vehicle [8].

3 Automotive Security Evaluations

As discussed in the previous section, modern vehicles can be open to various security risks. By applying in-depth security evaluations for an automotive IT system, for instance an ECU, potential security weaknesses can be identified and countered before an attacker can exploit this weakness in the field and causing real financial or even safety damages. The earlier such a security evaluation is done within the developer cycle the less costly and time-consuming it is and such security weaknesses can be found and be closed effectively.

Automotive security evaluations can be done in theory as well as in practice. Theoretical security evaluation can (and should) be done during virtually all steps of the automotive development cycle, ideally already from the very beginning, when only a description of the vehicular IT system is available. Subsequent security evaluations for the next product development iterations can then be done very efficiently based on the results of the previous evaluation. In fact, the need for theoretical and practical security evaluations does not end with series production of the corresponding IT system. Even in field the IT component might need a security re-evaluation (and eventually also new countermeasures) due to ongoing development of new attacks or new results from security research.

Practical security testing, of course, can only be conducted on an implementation of the target system, for instance with a first prototype.

It is important to note that security evaluation can support but not replace mandatory security protection measures such as security by design or security engineering.

4 Theoretical Automotive Security Analyses

Theoretical security analyses are becoming more and more common in the automotive context [9] and are applied to identify and understand the security weaknesses of an automotive IT system based on a paper-based evaluation of the corresponding system specifications and documentations. Depending on the level of scrutiny and the documents available, we differentiate between a more high-level *design analysis* and a more in-depth *threat and risk analysis*.

To conduct a **design analysis** of an automotive system, only a theoretical description of the system is needed. Depending on the level of detail of these descriptions, e.g. high-level protocol descriptions up to explicit specifications, the depth and accuracy of the analysis vary. The design analysis can identify systematic flaws in the system even in an early state in the development since high level descriptions can be adequate for a design analysis. Secondly, the results can establish trust in the soundness of the system's architecture. To achieve these goals, the documents are inspected for potential attack points, for instance, weak cryptographic algorithms, insufficient key lengths, or possible attacks due to bad interaction of different standard protocols.

To categorize the identified vulnerabilities further and to detect the most important flaws of the system that need to be fixed first, a **threat and risk analysis** can be applied to the system. Starting from the documents available, the system is analyzed and possible attacks identified similar to the design analysis. Additionally, the difficulty of the corresponding attack procedure is rated for each of the attacks identified. The rating takes into account amongst others the required time, the needed expertise of the attacker, the equipment, and the needed access level. Furthermore, the potential damage of a successful attack is estimated in terms of safety, operational, and financial impacts. Both values, the attack difficulty and the potential attack damage, result in an overall risk for a certain attack. Security vulnerabilities that result in attacks with a high risk are then critical candidates that should be fixed first.

Nonetheless, theoretical security analyses can neither find any implementation flaws or deviations of the implementation from the specification, nor detect vulnerabilities that are part of insufficiently documented specifications or flaws hidden in supplied components from third parties. To guard the system against such implementation issues, secure software development measures should be applied to the whole vehicular development process [10, 11]. But especially practical security testing, as described in the following section, can be used to identify possible vulnerabilities and cover the gap.

5 Practical Automotive Security Testing

Practical security testing can find implementation errors that could be exploited by an outside attacker, but also unspecified functionality and discrepancies to the specifications. Therefore, a thorough practical security test helps to establish trust in the soundness of the implementation. Furthermore, practical security tests help to estimate the actual difficulty of an attack against the target system. In general, practical security testing consists of at least four different steps as described in the following paragraph.

In the first step, **functional security testing**, tests all security-related functions inside the test system for correct behavior and robustness. This step is similar to general functional testing but with focus on security functionality. A careful execution of this test can find implementation errors, discrepancies to the specification, and especially unspecified functionality that all might result in a potential security weakness. The next step, **vulnerability scanning**, tests the system for already known common security vulnerabilities, for instance, known security exploits or (security) configurations with known weaknesses. **Fuzzing** goes even further and tries to find new vulnerabilities of an implementation by sending systematically malformed input to the target system to check for unknown, potentially security-critical system behavior. To test the security of the whole system, i.e. software and hardware, highly individual **penetration tests** can be applied in a last step. During a penetration test a “smart human tester” tries to exploit all the vulnerabilities which were found in the earlier steps in a “sophisticated way” based on many years of “hacking” experience with the aim to change the behavior of the target system.

For all the approaches the tester needs to have access to the actual software and hardware of the target system. Furthermore, for functional testing also the specification of the system is needed, and for all other methods supporting software, for instance remaining bus simulation, may be needed to run the hardware device. Moreover, special testing hardware and software is needed, for example, JTAG-debuggers or special signal generators. However, practical security testing, especially fuzzing and penetration testing, cannot give any assertion on completeness. Depending on the time and resources it is possible to miss larger systematic flaws. Hence, practical security testing cannot replace theoretical security analyses and should always be complemented by a theoretical analysis to identify possible attack paths.

After presenting a first overview about practical security testing, the following subsection gives some further details about practical security testing in the automotive domain. Even though practical security testing is still relatively new to the automotive world, there is a strong need to establish a testing process [12].

5.1 Functional Automotive Security Testing

Functional automotive security testing ensures the general compliance to specifications and standards of the implemented security functionality, for instance, encryption algorithms, authentication protocols, of a vehicular IT system. However, the algorithms are not only tested for correct behavior according to the specification but also for robustness. Furthermore, performance of (often computationally intense) security algorithms is tested to identify potential bottle necks that might affect the overall security performance. As a result, functional security testing ensures dependable security functionality and that a functional weakness does not create any exploitable security threats.

In many cases, standard implementations such as OpenSSL [13] are not suitable for use in the automotive domain due to various constraints, and therefore, a much wider spectrum of cryptographic and security relevant implementations are in use. Performance or size limitations play a role here but also safety standards such as MISRA-C [14] must be fulfilled. Furthermore, a wide range of automotive specific security protocols are in use, such as secure flash algorithms or secure communication, secure OBD, theft protection, and upcoming vehicle-to-x (V2X) communication. It is vital that those security implementations are subject to thorough functional security testing.

Functional security is usually achieved by testing official test vectors (if available) and running lengthy tests against reference (if available) or independent implementations. Many cryptographic algorithms contain specific corner cases which cannot be caught by this kind of testing but could lead to security vulnerabilities, for example subtle flaws in numeric implementations that trigger only in one out of 4 billion random cases. Many modern cryptography and security implementations further rely on secure random number generators. In order to gain trust into the security of such a random number source, extensive statistical testing is required. Finally, in the highly performance- and cost-sensitive automotive environment, performance testing can help with correct dimensioning of hardware or enable an optimal choice of security algorithms and parameters.

5.2 Automotive Vulnerability Scans

Vulnerability scans are used to examine all relevant applications, source codes, networks, and backend infrastructures of an automotive system for known security weaknesses from a continuously updated database of known automotive security vulnerabilities.

There are numerous different variations of vulnerability scanning. Firstly, the code of the software/firmware running on the system can be scanned, identifying, for example, buffer overflows and heap overflows by using static and dynamic analyses of the source code and compiler settings. This must be done on source level or on binary level. Secondly, the system can be scanned for open ports and interfaces and also for available services running on the interfaces. In automotive systems, this encompasses classical IT interfaces such as IP communication on Ethernet, Wi-Fi, or cellular internet. Scanning is especially valuable due to the fact that a whole range of operating systems, network stacks, applications, and libraries is re-used, where a large base of vulnerabilities is already known and can be tested automatically, as done in OpenVAS [15]. This concerns reconnaissance port scans, as well as deep scans of specific vulnerabilities.

The automotive bus systems such as CAN have no equivalent in classical IT and are a specialty in the automotive environment but they are highly standardized. This means that automatic scanning tools are well-suited to give a first overview. In this context, scans of diagnostic functionality are notable, as those are likely to contain weakly documented security critical functionality, such as development or debugging functionality. As a third form of vulnerability scanning, the configuration for the whole system can be analyzed to identify security gaps, e.g. access to critical functions for everybody without authentication or automated check for authentication. Vulnerability scanning ensures that a system is secure against known attacks, which can easily be tried out by attackers and therefore are very likely attacks.

5.3 Automotive Fuzzing

Fuzzing is a technique used for a long time to test software and IP networks by exposing the implementation to unexpected, invalid, or random input with the hope that the target will react in an unexpected way, and thereby, to discover new vulnerabilities. The reaction of the target can range from strange output over unspecified behavior up to crashes. However, fuzzing as a testing technique for automotive target systems is relatively new although modern vehicles have many similarities to common computer networks. In fact, ECUs can be viewed at as small computers running different software, that are connected by different network types such as CAN, FlexRay, or MOST. Hence, it is quite natural to come up with the idea to apply fuzz testing also to automotive target systems as part of the security testing process.

In general, fuzzing consists of three different steps: firstly the creation of the input for the target, secondly the delivery of the input to the target and lastly the monitoring of the target system to detect errors in the program flow. Since fuzzing is widely used in the computer world, fuzzing tools such as Peach [16] already exist. Peach has a powerful fuzz generator that can be adapted individually for different protocols, e.g. UDS. The input generated by the fuzz generator is then delivered to the target using the required transport protocol. The target system is now monitored to detect possible vulnerabilities. The monitoring process can range from inspection of the return values up to the usage of debuggers which observe the internal status of the target device. In the end, all identified unusual behavior has to be analyzed by an expert to detect exploitable vulnerabilities. Examples for such exploitable bugs are insufficient input validation or undocumented functionality, e.g. open debug or configuration interfaces. One famous example for insufficient input validation is the Heartbleed Bug [17] of OpenSSL, which allows reading out critical data since length parameters are not double-checked.

In the automotive context, fuzzing can be applied to diagnosis protocols, such as UDS, or to automotive network protocols, e.g. CAN, FlexRay, MOST or LIN. However, classical fuzzing targets, i.e. IP based networks, play an increasing role in modern vehicles. Hence, automotive security testing also benefits from experiences made in fuzz testing of classical protocols and modern software applications, e.g. cellphone apps.

5.4 Automotive Penetration Testing

Penetration tests start with general reconnaissance, which includes enumerating interfaces, determining components and their connections on the PCB, specifications available to a hypothetical attacker, and, in general, any information that can be helpful in further attacks. Using the information acquired in the first step, further attacks can be planned. A second step may include attacks of local external interfaces such as the CAN bus, Ethernet, USB, serial ports, or attacks on the hardware itself.

Such invasive hardware penetration tests are motivated by either IP protection or authoritative functionalities that rely on the integrity of the ECU against interests of physically present persons. Examples are theft protection, component protection, protection from odometer manipulations, feature activation, protection from false warranty claims from “tuned” vehicles, or safety functionality. One common method for a tester is to find overlooked or undocumented debug access interfaces or to gain access to ECU-internal interfaces such as memory buses. More advanced methods require etching open chip packages and accessing the actual silicon chip.

The specific forms of penetration testing are black-box testing, white-box testing, and grey-box testing.

For black-box testing, the tester is provided with practically no documentation or specifications, except information that could also be acquired by a real world attacker. The advantage of this method is that it results in a very realistic simulation of an attack. As a disadvantage, the penetration tester must spend a lot of time on basic reverse engineering and there is a good chance that deeper attack paths are not discovered because the tester did not circumvent easier first-line defense mechanisms, whereas an attacker may later break such defense mechanisms, by luck, because more information got public, because the state-of-the-art has advanced, or because he invested more resources than the tester.

For a white-box test, the tester is provided with full specifications and documentation for the device under test. This means he is able to specifically target weaknesses and has more resources available, which he does not have to spend on gaining information. Both reasons improve the efficiency of the test. The disadvantage of white-box testing is that the conditions are not nearly as realistic as in black-box tests giving a less reliable estimation of attack difficulty and likelihood.

Grey-box-tests represent a middle ground between black- and white-box testing. For a grey-box test, the tester receives partial information, concerning a specific sub-system that is in focus or information that a specific attacker such as an insider could have acquired. A step-wise approach is also possible, where the tester receives more information or access after having shown the basic presence and exploitability of vulnerability without having to fully develop the attack itself. This optimizes the ratio of test efficiency and realism.

6 Conclusion and Outlook

This paper showed the strong need for systematic automotive security evaluation and discussed different methods for theoretical and practical security evaluation of automotive IT components. We focused especially on practical security testing for automotive components such as automotive penetration testing since practical security testing is still relatively new to the automotive domain.

We believe theoretical and practical security evaluations will become a standardized and mandatory procedure, for instance as we know it from today's safety testing in ISO26262, to fulfill state-of-the-art product liability requirements and to protect various upcoming automotive business models (e.g. on pay-per-use basis). This of course requires serious efforts from OEMs, suppliers, and security experts to establish necessary automotive security testing expertise, testing standards, and testing infrastructures.

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Accelerated and Cost Effective Deployment of V2X Solution

O. Haran

Abstract V2X communication is making its way to series-production to fulfil the vision of zero-fatalities safety and enhanced mobility for lower emissions. V2X benefit is heavily depending on the technology penetration rate. The penetration will increase on two conditions: technology is cheap and can be introduced quickly. Following experience gained from several design cycles, Autotalks obtains a deep understanding of optimizing V2X system cost, fitting any vehicle architecture or retrofit device. The presented optimization methods cover pre-integrated software, optimal module partitioning and optimized chipset solution. Examples of addition to several vehicle architectures will be demonstrated. The paper will show that cost-effective V2X solution, added at low-risk and effort, is available now.

Keywords Vehicle-to-vehicle (V2V) communication · Advanced driver assistance system (ADAS) · Telematics control unit (TCU)

Glossary

ADAS	Advanced Driver Assistance Systems
CPU	Central Processing Unit
ECC	Elliptic Curve Cryptography
ECDSA	Elliptic Curve Digital Signature Algorithm
ECU	Electronic Control Unit
MCU	Microcontroller Unit
OEM	Original Equipment Manufacturer
TCU	Telematics Control Unit
RFIC	Radio Frequency Integrated Circuit
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything

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1 Introduction

V2X is a wireless technology enabling infrastructure to deliver data to vehicles (V2I) and vehicles to exchange information such as position and speed with other vehicles (V2V). It is using the 5.9 GHz band. Ratified standardization enables interoperability of communication, security and messaging.

V2X is the cornerstone for safety, mobility and riders convenience applications. Further in the horizon, Autonomous driving will be more achievable and reliable using V2X.

USDOT took the path of regulation, starting with advanced notice on new light vehicle rule-making. In Europe, V2X deployment is voluntary, based on signed understanding between most OEMs and suppliers. The fundamental success condition in both geographies is early availability of low-cost solution, allowing to accelerate V2X timetable for reaching a critical mass of V2X on the road.

The paper will answer the following questions:

- How to apply built-to-cost solution?
- How to quickly introduce solution to market?
- How to achieve that without compromising quality and reliability?

2 OEMs Requirements

2.1 Overview

OEMs requirements are diverse and resulted from different vehicle electronic architectures, different unit and antennas placement constraints and different business models.

2.2 V2X Solution Location

The most important system decision is the placement of V2X unit and antennas. The decision impacts the cost, wireless performance, applicability to other vehicles of OEMs and future usability of V2X technology for vehicle control.

The most popular locations are elaborated below:

Integrated V2X shark-fin antenna: by integrating the V2X solution inside the antenna, the solution cost is optimized. No expensive COAX cable and no high-frequency RF connectors are needed. Removing those consequently eliminates RF attenuation, and improves the wireless performance.

Integrated V2X antenna is suitable for OEMs having external antennas, installed at most of their vehicle line-up.

Roof antennas are small. V2X solution is forced into strict size constraints.

ADAS: V2X vision is accidents elimination. ADAS ECU is responsible for handling driver safety alerts. Sensor fusion integration doesn't mandate having the V2X located inside the ADAS ECU, but having a local fast connectivity is beneficial. In addition, achieving functional safety qualification is simpler if entire operation is performed in a single ECU rather than numerous ECUs.

TCU: external vehicle communications are handled by the TCU. Adding V2X could be a natural extension. The downside is that TCUs are typically not involved in safety critical aspects, and typically using Linux operating system without functional safety certification.

2.3 Supplier Eco-System

V2X is a complex technology. It involves antenna, hardware, security, positioning, software and integration with several components inside the vehicle. OEMs expect the Tier1 to take full-ownership, but it takes time until Tier1 is proficient enough to achieve that, and not always it makes economical sense.

For that reason, Tier1s may prefer to delegate full responsibility to its suppliers, in particular for the software part, and not to deal with complex integration of several sub-suppliers.

2.4 Low-Cost Solution

The entire value of V2X depends on its ability to be deployed in any vehicle, including the cheapest ones. The incremental V2X cost must be low to enable that.

It goes without saying that cost is the most important parameter.

3 Key Technical Requirements

3.1 Comprehensive Functional Automotive-Grade Solution

Without diving into the long list of technical requirements, the V2X solution must exist, must be fully functional, must not have any functional gaps, and must be AEC-Q100 qualified.

There is no justification for partial solutions or solutions not fully Automotive qualified.

3.2 Standard Compliance and Interoperability

These straightforward requirements assure that all V2X solutions can talk with each other. All solutions must be tested for standard compliance. All solutions must successfully pass public industry interoperability events.

Some functionality can be tested at the unit level, like message format. But few system properties, like wireless performance tests, which are impacted from the specific antenna of a specific vehicle, might require V2X testing while assembled inside vehicle.

3.3 Worldwide Support

Automotive market is global, and is attempting to minimize the differences between solutions to different geographies.

V2X specifications in US and Europe are different. IEEE1609 and SAE2735 are the basis for the American solution, while ETSI ITS G5 is the basis for the European solution. Harmonization group attempts to minimize the differences to utilize a single global hardware. This was mostly achieved but few inherent differences remain:

- Transmitter unwanted out-of-band emissions: Current European requirements cannot be supported with existing RFIC technology. An external custom filter is needed. A promising attempt is likely to relax the requirements, yet until the specification is officially altered, the filter is required.
- Dual channel operation: US deployment model assumes usage of a second channel for security management. The second channel isn't allowed to harm the availability of the safety communication. No similar requirement exists in Europe. V2X solution should have the ability to activate two concurrent channels in US, and to disable this functionality in Europe.
- GeoNetworking and Decentralized Environmental Notification Message (DENM): The European networking model is more complicated than the American one by including multi-hop communication for long distance and sustained alerts. In addition to the periodic safety messages, DENM messages increase the number of maximal transmitted messages per second. Signing capacity has to support the upgraded requirement, and CPU processing power has to be sufficient for handling the geographical routing.

3.4 Safety Critical Reliability

V2X information reliability is subject to two different considerations:

- Wrong local data processing: triggering a false alert risks safety of the driver.
- Corrupted or violated transmission: impacting the entire network, risking safety of many drivers.

Receive operation and application processing should be carefully tested under diverse conditions, including high network load. In the not so far future, V2X should be designed according to functional safety guidelines to allow vehicle actuation.

Transmit path has to assure data correctness under any condition. Transmission should not exceed the allowed rate, data elements in message should be valid, and secure message signature shouldn't be misused.

3.5 Secure Solution

It can't be ignored that public is concerned of V2X network security. A single successful attack may cause irreparable harm. Users may not agree to rely on V2X again.

V2X is employing public-key cryptography to authenticate over-the-air messages. The ECC family of algorithms was selected by the standardization bodies because of the small size of its signatures and keys. Signatures are calculated according to ECDSA using keys which are currently 256 bits long.

The two primary security functions are:

- ECDSA signing: attach a signature generated with a selected private key to an outgoing message.
- ECDSA verification: check the correctness of a received signature based on an already verified public key.

The implementation requirements from each function are totally different.

Signing must use secure, tamper-resistant storage preventing manipulation of private keys. No practical way should exist for extracting private keys from the V2X device. Storage should be sufficiently large to allow several years between keys replacement.

The requirements can be supported only by using a Smartcard IC device, also known as a Hardware Security Module (HSM). Such devices employ a tamper-resistant non-volatile memory serving as secure key storage, along with numerous tampering countermeasures.

Typical HSM devices are operating between –25° and 85° and aren't AEC-Q100 qualified. It is imperative to select HSM which is AEC-Q100 qualified.

Verification operation should simply satisfy performance requirements; there is no requirement for physical security. The performance parameter translates to the ability to verify all incoming messages for critical benefits: short latency, no potential security weak points, no need for algorithm selecting the messages to be verified and no potential usage of unverified data.

The minimal performance is 400 verifications per second, yet that doesn't assure that all messages are verified and some of the risks mentioned above are still valid. Full line-rate verification should complete 1000 verifications per second, which should be the baseline requirement for vehicle actuation application.

4 Cost-Effective Solution

4.1 Cost Contributors

Bill of Material (BOM) of V2X solution is composed from modem (RFIC + baseband) + CPU + security (verification + signing). Other functions, like positioning, are needed in the system but can be shared with other ECUs.

Development costs involve hardware design costs, licensing costs (if required) and software customization costs to the specific platform. Further costs are incurred in case the V2X solution is immature or partial.

Integration cost involves effort of modifying an existing design to support V2X addition.

Last but not least, testing cost should be considered.

4.2 Cost Saving Factors

BOM is reduced by using a tailor-made integrated chipset. Every mature technology eventually converges toward usage of a dedicated chipset achieving the best cost structure. Only the required functions are included in the chipset, avoiding unnecessary cost burden. Number of devices is minimized to eliminate unnecessary package and device testing costs. As a rule of thumb, a solution with fewer components is cheaper.

Customization costs are a major contributor to development costs. A generic platform fitting several ECUs with small changes minimizes the software customization costs.

Hardware modules are another method to reduce development costs. No need for hardware design, bring-up and development of testing environment. Companies lacking RF skills can accelerate time to market.

Integration cost is minimized if V2X has a small impact on the system. The cost is directly proportional to the amount of code lines that should be integrated. If the required code base for integration is huge, then integration effort is huge. If all of the software is pre-integrated on a different CPU, then integration cost is very low.

Obviously, testing cost is proportional to number of tests. Number of tests is multiplied if dependant functionality has to be verified. For example, if function A requires 6 performance tests, and function B requires 8 performance tests, then dependencies testing could lead to up to 48 tests, while decoupled testing requires only 14 tests. The test setup of dependencies testing is far more complex because scenarios are more sophisticated.

By having the V2X functionality mostly decoupled, as achieved by pre-integration on dedicated CPU, number of tests drop. Complex tests like measurement of message latency variation or high network load behaviour can be created using simplified scenarios.

To summarize, a blackbox solution is the key to reduce costs from all aspects. Particularly, if implemented as a HW module.

5 Quick Solution Availability

There is a great similarity between cost consideration and schedule considerations.

Obviously, the first parameter determining schedule is device availability. Using non-existing devices is not a good recipe for success.

The second parameter is engineering work. Using a module shortens board design schedule. Using pre-integrated software shortens coding, integration and testing schedule.

6 Case Studies

6.1 Adding V2X to TCU

A typical TCU contains main CPU connected to communication modules. At some cases, the CPU embeds some connectivity functionality.

Without pre-integrated solution, the CPU should embed significant codebase for V2X operation. The Tier1 needs to deeply understand V2X stack and testing method, and figure out any dependencies with existing software functionality.

Pre-integration solution eliminates all of that while providing flexibility of safety application partitioning, if needed, between the pre-integrated solution and TCU's main CPU (Fig. 1).

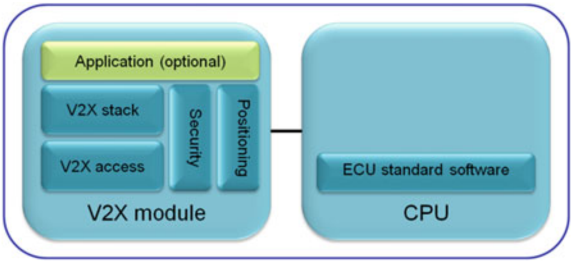

Fig. 1 System diagram of TCU with pre-integrated V2X module

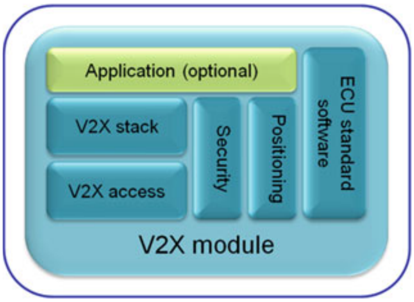

Fig. 2 System diagram of ECU running standard software on V2X module

6.2 Standalone V2X ECU

CPU of standalone V2X ECU is not performing other tasks, therefore integration is trivial if the solution is mature.

The only remaining challenge is vehicle connectivity. Connecting the ECU, typically using CAN, to the vehicle bus. Two options exist for that:

- Adding small MCU that already contains a specific OEM standard software, which is typically AUTOSAR based
- Integrating standard software on CPU integrated inside the V2X chipset.

The first option is quicker and easier, while the second option enables smaller and cheaper solution. Solutions with very limited size, like antennas, may be confined to use only the second option (Fig. 2).

7 Conclusion

The paper studied considerations for achieving accelerated and cost effective deployment of V2X solution. OEMs requirements are diverse, but none compromises on quality and high performance. V2X solution has to be flexible to support all requirements. The flexibility should be reflected in simple customization for reducing development schedule and overall cost.

Pre-integrated blackbox V2X module is the best solution for reaching accelerated and cost effective deployment of V2X solution.

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V2V and V2I Communications—From Vision to Reality

Vehicle-to-Vehicle, Connected Car, ITS

Maurice Geraets

Abstract Car connectivity will contribute to coping with future challenges such as growing urban populations, traffic jams, pollution and road fatalities. This paper exposes in brief NXP's view, technology and recent experiences in past and ongoing projects that will accelerate the deployment of V2X.

1 Introduction

The connected car is key to the future of automotive and mobility. As urban populations rise, issues such as traffic jams, pollution and road fatalities tend to increase. A viable solution to these global challenges is connected vehicles and infrastructure, creating an intelligent road network that is safer, greener and more efficient.

NXP has long realised the potential of the connected car and has participated in many of the earliest field trials of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I), collectively known as V2X.

Don't be fooled into thinking that the deployment of this technology is decades away. We see Intelligent Transport Systems (ITS) technology on the roads in just two years. Recently General Motors, Delphi and NXP announced mass production of securely connected cars with V2X communication by 2017.

ITS technology allows alerts to be delivered to vehicles from other cars and surrounding infrastructure, such as traffic lights and signage to alert drivers about potentially hazardous traffic situations even beyond the line of sight, optimally complementing Advanced Driver Assistance Systems (ADAS) like radar. Although this paper doesn't focus on (highly) automated driving, the application of V2X will be a key element for this too.

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Messages include blind-intersection collision, road condition hazards, road works warning, presence of emergency vehicles, stationary or slow moving vehicles, traffic jams and accident warnings, as well as traffic signals and signage indicators.

2 V2V and V2I in Action

The potential of this technology is being taken seriously by companies and governments across the world. Europe launches the Cooperative ITS Corridor, a 1,300 km stretch of roads through Austria, Germany and the Netherlands fitted with the latest V2X technology designed to bring enhanced safety and reduce congestion. The Netherlands, Germany and Austria have signed a Memorandum of Understanding to deliver this project in 2015. And this is just one of the many ITS projects taking place across the globe.

For example, several industry and technology partners working together with the Dutch government have proved via trials the value of ITS technology in reducing "phantom" or "shockwave" traffic jams—congestion caused by driver behaviour and braking rather than accidents or lack or road capacity. "Spookfiles" as this is called in Dutch account for 20 % of all of traffic jams in the Netherlands and over 30 % of jams on the A58 between Eindhoven and Tilburg. This is why that particular road has been chosen for a unique ITS project that is applying different connected and cooperative solutions—both roadside and in-car—to help find address this traffic problem.

Other projects using the technology include the simTD trial in Germany, Connected Vehicle Safety Pilot Program conducted by the University of Michigan Transportation Research Institute (UMTRI) in the US and the SCOOP project in France. Furthermore there is a trial soon to begin in Singapore which will look into the implementation and also other potential use cases for ITS. The one aspect that binds these projects together is their reliance on V2X technology.

3 Security in the Connected Car

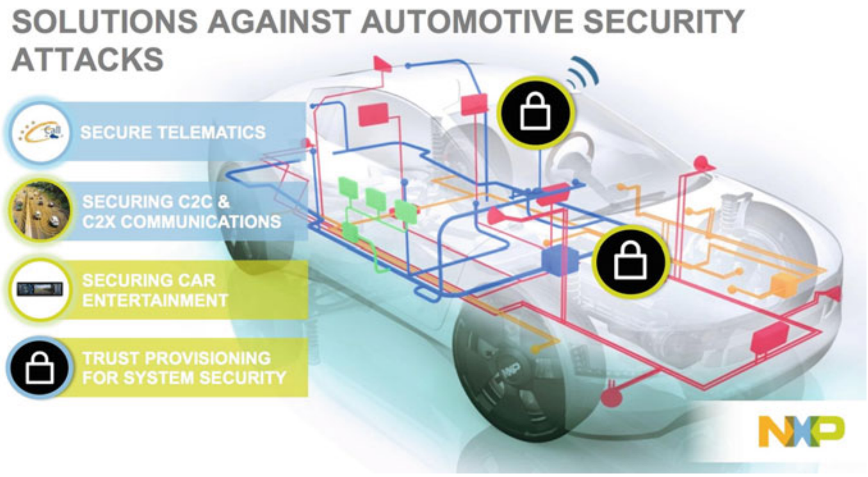
For successful implementation security is a vital element of any connected car solution. V2X works by creating ad hoc data exchange networks between the vehicle and environment—in other words, independent, self-organising networks of mobile users. The range of such systems is up to 1500 meters and transmission protocols derived from the common WLAN are used (i.e. WLAN standard IEEE 802.11p).

As with any other wireless LAN, communication is exposed to security risks that must be guarded against. The quality and integrity of data has to be ensured. Intelligent vehicles must be able to detect whether data has been altered and falsified for any reason when collected or transmitted. Wrong or defective data can block the applications on which they are based or render them ineffective—in the worst case becoming a genuine safety risk. For instance if incorrect data misleads a vehicle into incorrectly recognising the speed of the vehicle driving ahead of it, there could be fatal consequences. So mechanisms need to be integrated that can detect bad data and remove it from the communication circuit.

Security automotive solutions encrypt, authenticate and secure data at chip level. Using a set of security keys the car can determine if that the data really originates from a trustworthy vehicle. Another important element is privacy; security elements randomise the signature of vehicles so that an individual's driving behaviour cannot be tracked by other vehicles.

4 Setting the Standard

The final hurdle facing mass adoption of V2X was the setting of global standards. Members of the Car2Car consortium, the Amsterdam Group, ETSI and the High-level ITS Advisory Group to the European Commission have realised the essence of standardisation, the need to remove obstacles for applying V2X and the importance of deployment acceleration initiatives. In a few years' time the world of driving as we know it will undergo a revolutionary change and that change will be built on the secure car2x solutions, provided by NXP.



Part III
Technical Progress—ADAS

Model-Based Design for the Development and System-Level Testing of ADAS

A. Kim, T. Otani and V. Leung

Abstract Advanced driver assistance systems (ADAS) are becoming ubiquitous, and the safety of these systems is more important than ever. Engineers are incorporating new technologies—including different sensing modalities, data processing and fusion algorithms, as well as enhanced control and automation systems—leading to increased system complexity. In order to manage the complexity of these systems and address the issue of safety via extensive testing, it is vital to have an integrated environment so that different technological components can be incorporated and tested at a system level. We present such a solution in this paper. The proposed framework is based on Model-Based Design, enabling vision algorithms and control strategies to be developed using the same platform. Furthermore, software-in-the-loop (SIL) testing can be achieved via automatic C/C++ code generation. To close the loop at a system level, the environment must also be modeled. Environmental conditions include the weather conditions, the type of sensor used which affects the input data for the vision algorithms, as well as the vehicle dynamics model. This aspect is also addressed in this paper. We focus on lane-keeping as an example to illustrate different aspects of the framework.

Keywords Advanced driver assistance systems · Model-Based Design · System-level testing

Glossary

ADAS	Advanced Driver Assistance Systems

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IPCV	Image Processing and Computer Vision
FSM	Finite State Machine
ROI	Region of Interest
SIL	Software-in-the-Loop

1 Introduction

ADAS are complex systems. At a high level, ADAS need to be aware of their environment through sensing, and to react to the sensed data in both predictable (such as in normal motorway traffic) and challenging (such as in heavy traffic on a rainy evening on a windy road) circumstances. The environmental awareness comes from processing data captured by multiple possibly heterogeneous sensors; the reaction to the sensed data corresponds to the control of the vehicle. To manage this complexity, engineers need a framework that is sufficiently flexible such that both the data processing and the control components can be incorporated simultaneously. It should also support modeling of environmental conditions and similar factors. Furthermore, it should serve as a test harness for experimenting with different inputs. Finally, as ADAS are to be used in vehicles, the framework would ideally enable software and even hardware implementation requirements to be taken into account.

In this paper, we describe such a framework, based on Model-Based Design, that is capable of fulfilling these requirements. We will show how this framework can accommodate different technological components, how the environment can be incorporated into such a framework and also how software implementation requirements in the form of software-in-the-loop testing can be addressed.

The paper is organized as follows. Section 2 describes the motivation for using Model-Based Design, and the high-level components for ADAS. A lane-keeping system, which works to maintain the vehicle within the lanes of demarcation on the road, is used as an end-to-end example. Section 3 examines image processing and computer vision technologies in ADAS. SIL testing is illustrated on the lane detection algorithm. Section 4 discusses briefly the control and command algorithms. Section 5 presents the lane-keeping system as a whole from a system point of view. Conclusions are drawn in Sect. 6.

2 Model-Based Design

Model-Based Design begins with a system model that captures requirements. It is an executable specification: “executable” because it can be simulated as part of the design process, and “specification” because the model also serves as documentation of the algorithms [1]. The design is therefore linked directly to the requirements.

Fig. 1 The high-level components in the Model-Based Design lane-keeping application framework

With Model-Based Design, one can simulate a model, perform rapid prototyping, and explore design trade-offs. Software and hardware implementation requirements, such as fixed-point and timing behavior, can be incorporated into the design. Test benches can also be created for system verification. When the design is ready for implementation, code can be automatically generated for embedded deployment, minimizing hand-coding errors.

Model-Based Design is ideally suited to ADAS, as active safety systems are complex multidomain, multirate systems, involving both sensing (vision in the lane-keeping example) and control components running at different sampling rates. Figure 1 shows a high-level view of the framework in this application. This framework supports the design and validation of these components under different test cases—an important consideration as the system must be as robust as possible in challenging and possibly unpredictable situations. It enables engineers to ask and answer "what if" questions. For example, what if the lane markings are not detected accurately? What will be the consequences on the lane-keeping application, and the trajectory of the vehicle? Importantly, it also enables components of different sampling rates to be accommodated in one environment—the control component being at a much higher sampling rate that the vision component in this case. In addition to functionally testing the system, trade-off studies can also be performed to optimize system-level performance.

As ADAS become more ubiquitous, various active safety systems are gradually becoming subjected to regulation in different countries. These include advanced emergency braking systems and forward collision warning systems, as well as lane departure warning systems. Such regulation further highlights the need for systematic closed-loop testing.

3 Image Processing and Computer Vision

ADAS make use of many on-board sensors, including vision, LIDAR, and GPS, for different tasks. Here, we focus on image processing and computer vision (IPCV) applications using data from vision sensors. Specifically, we concentrate on single-camera configurations.

IPCV applications in ADAS include detecting objects of interest (such as vehicles, bicycles, pedestrians, and road markings), tracking other road users, stabilization, and lane-keeping.

A popular method for object detection is to use a detector trained for a specific purpose. The training starts with a database with both positive and negative examples of the object to be detected. Features are extracted, which are then used in a machine learning framework for training the detector. For example, a popular pedestrian detector is the HOG detector [2].

Tracking is the maintenance of space-time continuous trajectories of objects of interest. Tracking methods can be grouped into two main classes: motion-based tracking and feature-based tracking. Motion-based tracking relies on using a motion model of the object, for example at constant velocity. The Kalman filter [3] is a well-known example. Feature-based tracking, on the other hand, relies on detecting and extracting features in each image, and matching the corresponding features in consecutive frames. An example is the Kanade-Lucas-Tomasi (KLT) feature tracker [4–6].

Stabilization refers to the removal of movement introduced into the video due to vibrations of the camera, and is important as a preprocessing step to subsequent image and vision processing. This can be achieved using either template matching [7] or feature-based methods.

In this paper, we concentrate on the example of lane detection, the vision component of the lane-keeping application. The algorithm is illustrated in Fig. 2. For each image, the region of interest (ROI) is first delimited, and the road markings are detected in image space using edge detection. Here, the variation in the width of the road markings due to projective distortion is taken into account. Once the line segments are detected, they are transformed into world coordinates using a pre-calculated homography. A random sample consensus (RANSAC) method [8] is then applied, starting from the bottom of the figure and moving to the top to obtain bounding boxes. The center points in each of the boxes are used to fit a third-order polynomial. The fitted lines can then be used as an input to the control algorithm.

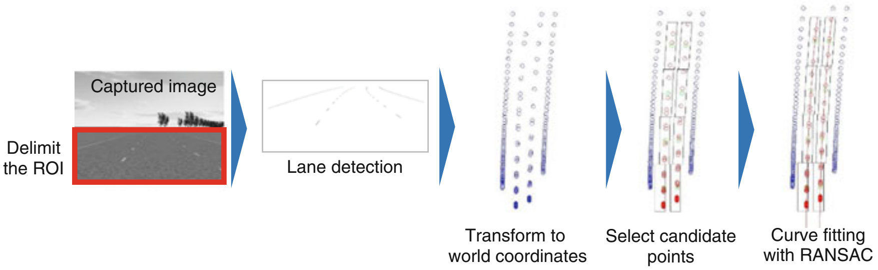

Fig. 2 Lane detection vision algorithm for lane-keeping

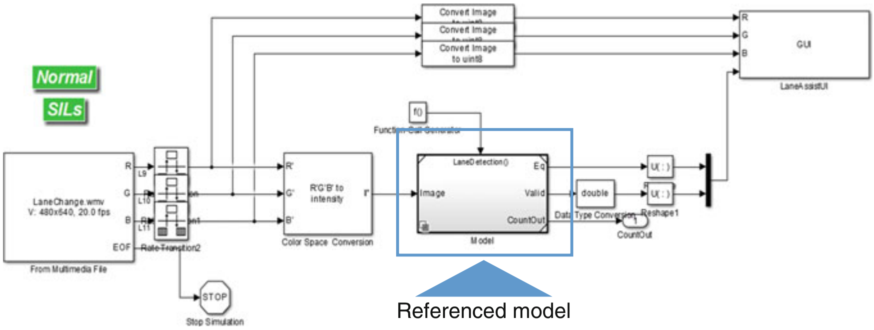

Fig. 3 Lane detection algorithm in a Simulink model

We began the development of the lane-keeping system with Model-Based Design by implementing the lane detection algorithm as a MATLAB Function block in Simulink [9]. This design choice of using a MATLAB Function block was made as MATLAB [10] is a flexible language with a debugging tool and visualization capabilities. Furthermore, it can be directly integrated into Simulink.

The Simulink model for the lane detection algorithm is shown in Fig. 3. The lane detection block is an instance of a referenced model. A referenced model can be considered as a “library”, where the model can be used many times without having to redefine it. Of its many advantages, arguably the most important is its modularity, as it can be developed independently from the models that use it.

From the point of view of testing, this Simulink model can be considered as a test harness for the lane detection model. The algorithmic implementation in the lane detection block is fixed—test data and visualization are added around it.

While the algorithm is ultimately to be deployed as embedded software, the first step is to perform validation in a simulation environment. This step is not addressed here, but the aforementioned test harness can be used for such a purpose. The next step is to perform software-in-the-loop (SIL) testing, in which the source code (written manually or generated automatically) for the algorithm or the component of interest is incorporated in the model. This allows the verification of numerical equivalence before any hardware implementation is undertaken. SIL testing can be introduced early on in the development cycle, even before hardware is available.

When the source code is written manually, an S-function can be used to incorporate it in a Simulink model. For code and blocks native to MATLAB and Simulink respectively, C code can be generated automatically, and the behavior of the generated code can be verified without modifying the original model.

Since it is possible to execute a referenced model in normal mode or as source code (i.e. in SIL mode), it is straightforward to perform SIL testing in Simulink. In the lane detection example, the outputs of the original referenced model executed in normal mode and in SIL mode are verified to be equivalent.

4 Control

In a lane-keeping application, the purpose of the control algorithm is to keep the vehicle within a lane by controlling the steering. The controller is made up of three main components: the mode selector (for determining the conditions under which the active safety system can be activated), the risk assessor, and the steering angle compensator. The steering angle compensator contains two main parts: a classic feedback steer angle determined by the heading and the lateral offset, and a feed-forward steer angle determined using curvature and vehicle speed [11].

The mode selector of the controller is realized as a finite state machine (FSM). Specifically, the tool used is Stateflow [12], which is supported by Simulink. The three states are:

1. System off: The system cannot be activated.
2. System ready: When certain conditions are met, such as the input of the vision processing being valid, the system can be turned on.
3. System on: The system is activated, if the vehicle speed and the lane detection are valid.

An illustration of this is shown in Fig. 4a, with the corresponding Stateflow implementation in Fig. 4b.

Once again, a referenced model can be created for this and used in a test harness, as shown in Fig. 5. The idea is to use an exhaustive test set to examine the functioning of the model, and that all the branches in the state machine are covered. Model coverage is an important aspect as this is required by certain safety standards, including ISO 26262. The construction of the test set can be achieved using the Signal Builder block in Simulink. The coverage of the FSM can then be traced and examined.

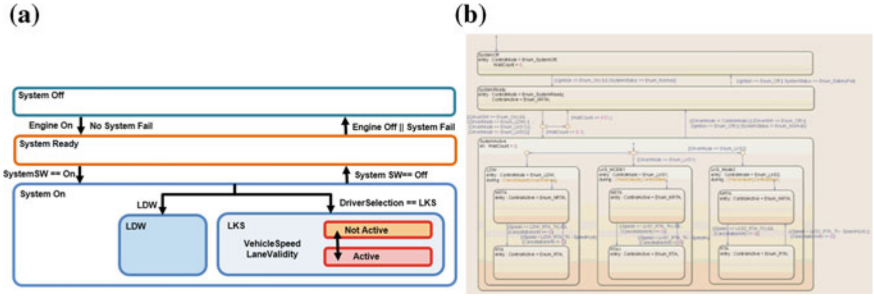

Fig. 4 **a** Illustration of the three states of the mode selector in the controller. **b** Corresponding implementation in Stateflow

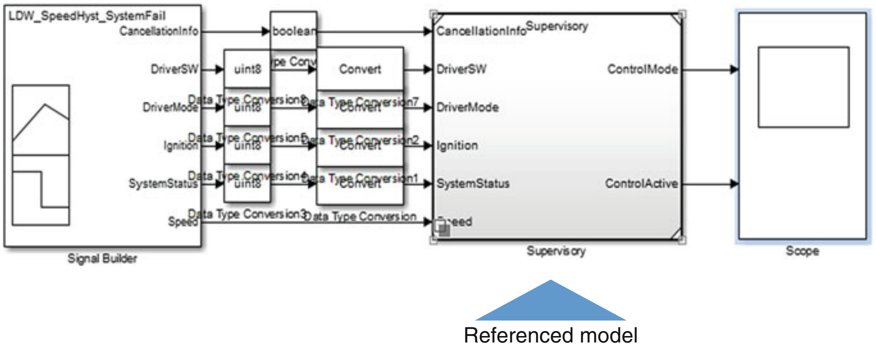

Fig. 5 Test harness for the mode selection FSM

5 End-to-End Lane Keeping System

Having examined the vision and the control components, the next step is to close the loop with the environment in which such a system would be deployed. Doing so in a real environment straightaway is not recommended, as it is expensive and potentially dangerous. Instead an environment simulator can be used. In this case, we use the software PreScan [13], which is designed for simulating the environment for ADAS and active safety systems. This allows realistic road and weather conditions, as well as sensor (in this case, a camera) characteristics to be defined.

At this point, it is useful to consider Model-Based Design in the context of the standard V-model (see Fig. 6). In Sects. 3 and 4, referenced models were created for the vision and the control algorithms, and were used in the respective test harnesses. At the level of system integration, reference models help users define the interfaces between modules when integrating them in the design process, and facilitate building the system-level integration test environment without additional effort. The end-product—an end-to-end lane-keeping system—is the result of this process.

The environment of the lane-keeping application, including roads, buildings, and trees, is defined in PreScan, as shown in Fig. 7a. Figure 7b shows the sensor model including its location, its field of view, and its characteristics. The different points of view of the scenario are shown in Fig. 7c.

By closing the loop, system-level simulation can be performed. This is vital as it allows the verification of the vision-control interface and the examination of the influence between the two components. For example, questions such as “what will happen to the control of the vehicle if the vision algorithm returns an inaccurate result?” can be answered.

The scenario defined in PreScan is encapsulated in blocks in Simulink. These blocks correspond to the vehicle dynamics as well as the camera model. The complete model is shown in Fig. 8.

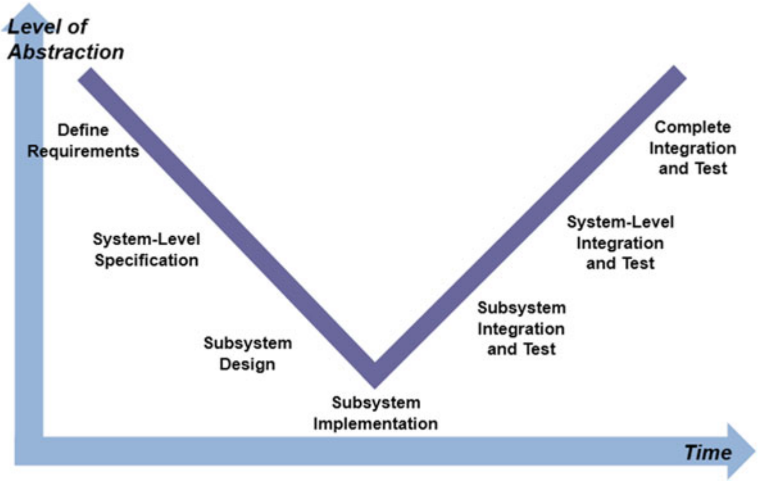

Fig. 6 The different stages of the MBD process represented in the standard V-model

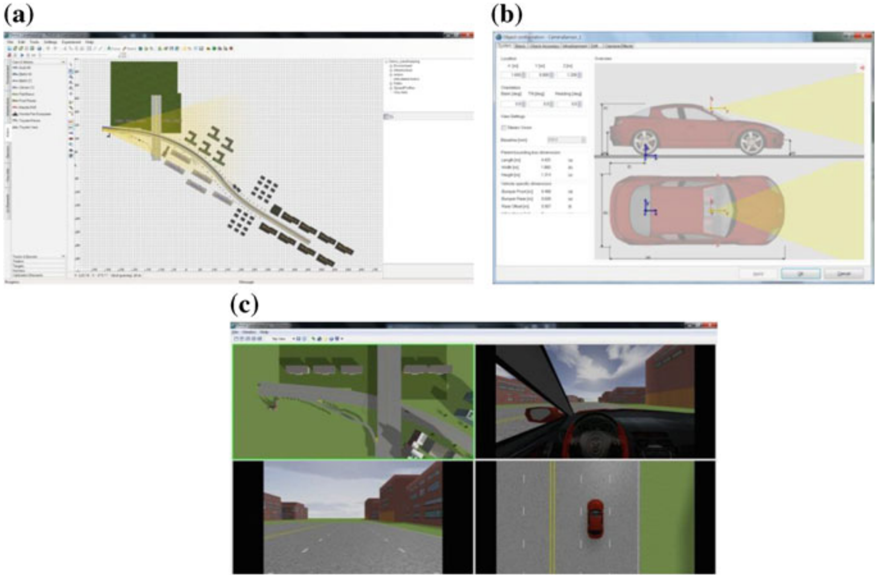

Fig. 7 **a** Simulation environment defined with PreScan. **b** The car model. **c** Different viewpoints of the scenario

The execution of the model starts a cosimulation between Simulink and PreScan, with the two software packages running interactively. The outputs of this model are shown in Fig. 9. In Fig. 9a, different viewpoints in PreScan are shown. Figure 9b shows a graphical interface developed in MATLAB, in which the output of the

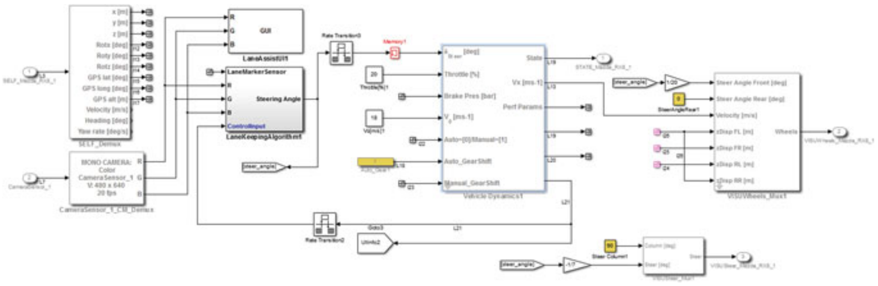

Fig. 8 Complete Simulink model of the lane-keeping system, including blocks automatically generated by PreScan

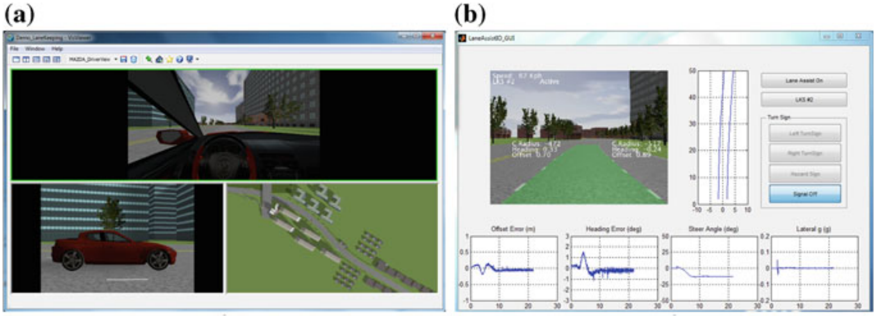

Fig. 9 The outputs of the system-level model

vision algorithm, the errors, and the steer angle returned by the vision module as the command to apply to the steering wheel are displayed. This provides a complete environment for the test and validation of the end-to-end system.

6 Conclusion

In this paper, we presented a framework for using Model-Based Design for the development and system-level testing of ADAS. The framework is well suited to this endeavor as it accommodates complex multidomain systems and can be used from the earliest design of the system up to the stage of production code testing, taking into account software and even hardware implementation requirements.

Lane-keeping was used as an end-to-end example. It comprises the vision and the control components, as well as the simulation of the environment for closing the loop. In terms of testing, software-in-the-loop testing was illustrated on the lane detection and the supervisory algorithms. The end-to-end system model also acts as a flexible test bench for different inputs and environmental conditions.

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Basis Autonomous Driving Functionality "Cruise4U" Economic Cruise Control (ECC) Based on Series Production Sensors

Joachim Mathes and Karsten Schulze

Abstract This paper looks at the implications on the interfaces between the different domain levels and vehicle control system for highly automated driving (HAD). Scenarios or scenes provide the basis for this new development process. Using these scenes, a set of function specifications can be compiled that cover all possible use cases. Implementation of this type will in future demand to an even greater extent that a function is first developed without considering implementation before it is then distributed over the target system with different controllers. And, moreover, higher demands are placed on the physical accuracy of the data provided by the domain management system compared to today's assistance systems.

1 Introduction

Highly automated driving (HAD) is a key topic in the future of transportation in general. In the case of the passenger car, automated driving is seen as a provider of enhanced comfort and convenience, but also increased road safety. Beyond the optimization of individual travel efficiency, it will save fuel by harmonizing road speeds to a greater extent [2]. Hence, HAD is an important instrument for green driving.

This paper focuses on the requirements for highly automated driving on motorways, a system we call "Cruise4U". Or, in more technical terms, Economic Cruise Control (ECC), as an enhanced version of the Adaptive Cruise Control (ACC). As a key differentiator over ACC, this system detects and decides about passing opportunities and is performing the lane change on its own in order to

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maintain a constant speed flow. Therefore, it is necessary to impose requirements regarding communication interfaces of powertrain and chassis systems as well as knowing vehicle specific characteristics for function calculation.

2 Challenges and Requirements Coming from ECC

In addition to surround sensors, steering system and brakes, the powertrain is an element in the overall system. The superordinate control system for automated driving gives the powertrain coordinator information on output torque and vehicle speed which is then converted into signals for controlling the combustion engine, transmission etc.

The implementation of the ECC function implies several challenges and boundary conditions:

- partitioned functional requirements on the basis of the specific subsystems
- despite the increased CAN communication, the safety concept must allow for message runtimes
- calibrating the different control units—an activity which in part is split among different development departments—has to be ensured

The integrated function concept in highly automated driving is geared towards the chronology of a traffic situation, from driving along safely, the occurrence of a critical situation to restoring the safe state. The sensor and actuator concept must be devised in a way that makes it effective almost through 360° around the vehicle.

Merging sensor data, evaluating relevant vehicle data and activating the actuators demand a reliable network and robust configuration of the associated control units. The complexity of multi-sensor functions for highly automated driving makes the individual surround sensor the central and therefore critical element in the entire function chain. This is illustrated above all by its limited substitutability. If the decision is taken at an advanced phase of a function development project to install a different sensor, it may be necessary to repeat many development steps as far back as powertrain level or even restart the development process more or less from scratch.

A similar challenge is the scalability of such systems, where depending on the chosen feature set, different sensors need to perform similar tasks without a perceivable effect on end user function.

Developing and, above all, calibrating surround sensor functions is a complex and challenging process that demands much specialist knowledge and the experience of individual experts. However, the expertise that is needed cannot be described in a process. Individually ascertained calibration results cannot be applied directly and are not fully reproducible. To resolve the tradeoff between ever-cheaper and therefore ever-more widely used surround sensor functions on the one hand and costly and complex function development on the other, it is necessary to rethink the whole approach—a new development process is needed.

What are the demands placed on such a process? The cost of development, calibration and validation is to be reduced. Function performance is to be consistent across all model ranges and component suppliers. Functions must also be made easier to develop and distributed over several control units and suppliers within a vehicle.

3 Example Development Procedure in ECC Scenarios

Scenarios or scenes provide the basis for this new development process [Weh11]. Here, a scene is a sequence of movements on the part of those involved in a driving situation. From a simple pass-by, passing another vehicle or parking maneuver to driving from one town to another, everything is conceivable. The scope of a scene is determined by what is relevant for the function. These scenarios accompany the entire development process from the requirements analysis to the release tests.

These scenes can form the basis for evaluating the development results, particularly also at the interfaces to the various domains. As a prerequisite, scenes must be identified in accordance with their targeted behavior. This means that for each scene it is necessary from the outset to define the way in which the function is to act. It must be ensured that the misuse-case scenarios are covered in addition to the use-case scenarios (Fig. 1).

Using these scenes, a set of function specifications can be compiled that cover all possible use cases. The scenarios can also provide the basis for representing sequences within driving situations and describing sensors with their properties (e.g. field of vision, installation site, measurement accuracy). This makes it possible to define requirements in relation to the sensors, sensor data merging and algorithms as well as the requirements on longitudinal and transversal dynamics.

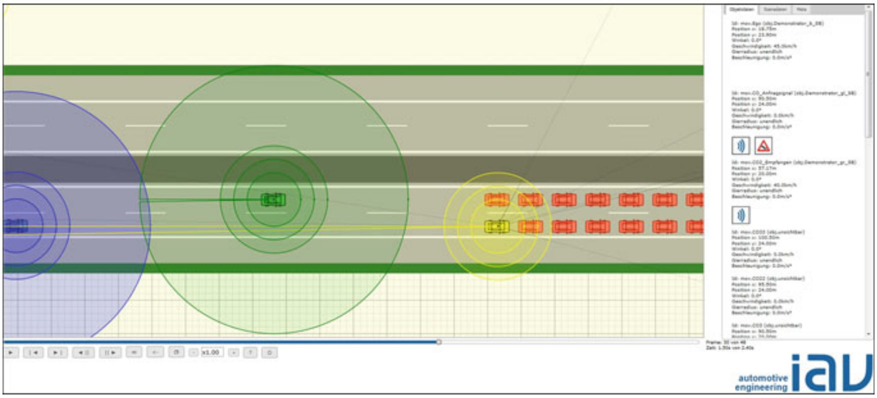

Fig. 1 Example of a scene evaluation

Apart from describing and reflecting sensor properties, simulating the sensors also plays a key part. The synthetic sensor data this produces is used in developing algorithms early on in a project. Proceeding from the scenes, it is possible at a later stage to create a set of tests for examining the algorithm's performance. A test case catalogue can be derived from this common scene base for final vehicle testing.

4 Approaches to Reflecting Distributed Drive Functions in Relation to Highly Automated Driving

Seen from the angle of highly automated driving functions, the changed functional spectrum gives rise to new demands on the interfaces to the various system domains. Decomposing functions in highly automated driving produces two main functional interfaces can be identified: Requirements on comfort functions as well as Requirements on emergency functions. As far as their composition is concerned, these two interface blocks differ in terms of Complexity, Validation input, Relevance to functional safety, Modification input and Cycle-duration.

With regard to availability and robustness, both function blocks come with a 100 % requirement, i.e. no systematic non-availability of the resultant system or no systematic change in behavior must be induced by a fault. The difference lies solely in the requirement of performance and reliability. The requirement on the comfort functions is that all possible use cases be implemented almost in full. Although performance of emergency functions is limited to a few use cases, a 100 % requirement is placed on them from the aspect of reliability. In the case of highly automated driving, this means that wherever possible the function prevents an accident from being caused (Fig. 2).

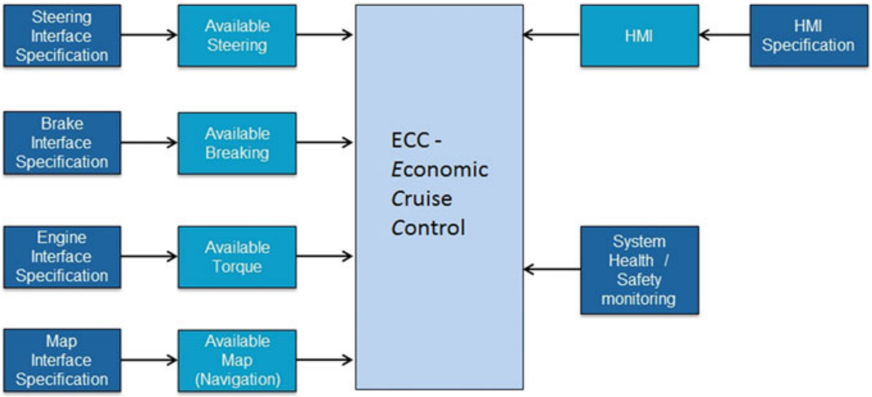

Fig. 2 Requirements on interfaces ECC function

Proceeding from the scenario-based function development approach, this means the following in terms of specification depth:

- Comfort functions: high number of driving scenarios with a relatively large parameterization bandwidth
- Emergency functions: small number of driving scenarios with specific parameter requirement

Implementation of this type will in future demand to an even greater extent that a function is first developed without considering implementation before it is then distributed over the target system. Only on the basis of this approach will it be possible to integrate and calibrate integral vehicle functions, such as highly automated driving, quickly and effectively with respect to comfort and safety requirements. Implementing previous system-specific functions, such as central powertrain coordinators, must undergo fundamental revision.

5 Providing Domain Control Data for ECC

Comfort functions are generally expected to behave in a reproducible way, and perform in the desired manner despite disturbing cross interactions. In most cases they are predestined for closed-loop control. Familiar examples include idle-speed control, load-reversal damping and cruise control from powertrain management. Conversely, emergency functions are expected to give an immediate response. Waiting for a control function to reduce a deviation in transient operation could take too long. In specific safety incidents it may be altogether appropriate to accept less comfort, higher emissions or component damage if this can prevent something worse (e.g. an accident involving other road users).

This is illustrated by two simple use cases. Controlling vehicle speed is a typical comfort function of the engine control unit. Engine torque is adjusted to maintain a given road speed. Closed-loop control is configured in a way that leaves control quality similar despite varying terrain topologies and vehicle loads. Implementing it in the engine management system guarantees fast response times and stability of the control loop without overshooting or possibly even oscillating adjustment processes. Target speed is defined by the driver at a control switch or, in the case of automated driving by the HAD controller.

Incidentally, moving the entire cruise control system into the vehicle's master computer would make little sense. Because the vehicle's master computer would then have to calculate a desired engine torque from the control differential between target and actual speed, communicate this to the engine control unit via a serial bus with its variable latencies, then "wait and see" how the vehicle responds and take any necessary corrective action. A control loop of this type would be far slower than a conventional solution and would have drawbacks over such in terms of control quality and correcting disturbing variables.

Let us stay with cruise control to address another matter. How does a superordinate driving strategy know which physical limits it can move about in? And what must it know at all? Looking at scenarios helps to configure the overall system here too. Let us consider a situation where the vehicle leaves an urban area and accelerates to the permissible maximum speed on the country road.

Scenario 1 The automated driving strategy defines the target final speeds.

This case is gratifyingly trivial and easy to realize with today's state of the art. On leaving the urban area the cruise control target value jumps from 50 to 100 km/h. The engine control unit's cruise control system accelerates the vehicle, with the dynamics of the acceleration cycle having previously been defined in the engine management system on the basis of comfort and economic aspects. There is no need to inform the superordinate driving strategy of the powertrain's operating limits.

Scenario 2 A slower vehicle is to be passed on leaving the urban area, whereby the passing distance and passing time must be known before the passing maneuver on account of oncoming traffic a short distance ahead.

This scenario can be of any complexity. It is obvious that the decision matrix for passing must be completely integrated in the superordinate driving strategy. How fast can the vehicle accelerate? Will the vehicle being passed keep to its speed? What speed is oncoming traffic driving at, how far away is it still? Is there a downhill gradient or incline ahead? How heavy is the driver's own vehicle? Can the passing maneuver be completed safely? Strictly speaking, this is now no longer just one scenario alone but several nested and interrelated ones.

For this situation, the powertrain management system must provide three key items of data. Besides the actual vehicle speed and current tractive power, maximum tractive power must also be communicated. Instead of tractive power, it would also be possible to send the current and maximum values for engine speed, engine torque and transmission gear step if these data were to be converted into a value for tractive power in the superordinate driving strategy.

Whereas the engine's speed range and gearshifting are a matter of design, maximum possible engine torque is influenced by ambient conditions. Primarily, these include water temperature, intake air temperature and air pressure. These dependencies are usually determined during the production development phase and stored in the engine control unit for component protection reasons so that calculation of a maximum possible tractive power should become possible in a limited projection period.

However: These load limits have previously been used merely to limit engine power output. Whether or not the data stored in the control unit actually matched the exact physical values has been less relevant because the sole aim was to prevent the engine from operating above its load limits. If these load limits become key values of a highly automated driving strategy in future, they must be physically correct. The lives of vehicle occupants could depend on them.

6 Summary

Describing automated driving with the aid of scenarios makes it easier to describe the superordinate system. The scenarios provide the basis for deriving function modules for the vehicle control units concerned. As compatibility with conventional drive systems without automated driving functions continues to be given, functions can be reused to a large extent. However, higher demands are placed on the physical accuracy of the data provided by the powertrain management system.

All the same, it is expected that powertrain management will become a subordinate assembly in an overall driving strategy as highly automated driving becomes more and more prevalent. This altogether represents a paradigm shift in development. For the powertrain developers it may be consolation to know that without their powertrains even the best highly automated driving strategy will not work.

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Standardization of Generic Architecture for Autonomous Driving: A Reality Check

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Abstract Autonomous driving requirements regarding safety, redundancy and performance lead to an increasing number of on-board heterogeneous equipments (sensors, actuators and processing units). Systems with the highest levels of autonomy must handle a large number of real-life situations, some of them being quite challenging. Interactions between sensors, perception, planning, control and actuators are fundamental to ensure operational efficiency while providing both proactive safety and timeliness execution. To address these constraints, appropriate design patterns are required to implement complex and robust decisional architectures. As a matter of fact, current system vehicle standards do not address these design neither patterns nor their underlying complexity. Based on various experiences in defense and civilian domains, we will present a critical review of ongoing standard developments and propose a generic design pattern to qualify autonomous vehicles architectures.

Keywords Autonomous architecture · Layered planning · Standardisation · Safety

Glossary

ADAS	Advanced Driver Assistance System
ADL	Architecture Description Language
AUTOSAR	Automotrive Open System Architecture
DDS	Data Distribution Service
GVA	Generic Vehicle Architecture
ISO26262	Road Vehicles—Functional Safety
JAUS	Joint Architecture for Unmanned System
PLEVID	Platform Level Extended Video Standard

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ROS	Robot Operating System
UGV	Unmanned Ground Vehicle
US NREC	US National Robotic Engineering Center

1 Introduction

An autonomous car, also known as a driverless car, self-driving car, or robotic car is an autonomous road vehicle capable of fulfilling the transportation capabilities of a traditional car with minimal human input [1]. As an autonomous vehicle, it is capable of sensing its environment, and to perform navigation, guidance and control. Autonomous cars technology can improve our life with reducing both car accidents and traffic congestion. It can also discharge the driver from the monotonous daily driving, during which he can perform more productive tasks or just relax. From market point of view and end user acceptance, after automated parking manoeuvres and autonomous emergency braking, the next ADAS (Advanced Driver Assistance System) functions go one step further toward the automated driving vehicle (see Fig. 1).

Similar functionalities are expected for first responders, civilian security and defense autonomous vehicles. In those areas, Unmanned Ground Vehicles (UGV) must fulfill complex missions in spite of an unknown environment, resource constraints and with limited human interventions.

These autonomous systems must strongly adapt to their environment, whatever the circumstances are. The architecture design has to deal with perception, data fusion, mission planning and control. It must also scale up according to time frames and environment complexity. Minimizing human intervention in the system loop exacerbates the classical requirements of safety and availability. Also, such systems need close loop interleaving between embedded operation, situation awareness, planning and decision with finer grain real time control and command.

Various architectures have been developed by research teams in the framework of the DARPA Grand Challenges (2004–2007) [3] and in many European funded projects like HAVE-It [4] and V-Charge [5]. In Defense and Aerospace, many relevant architectures have been also proposed by NASA (see Remote Agent

Fig. 1 End user acceptance of new functions

Architecture [9]) or ESA [10], and the US NREC, and through the UGV Demo I/II/III.

After presenting a classical decisional architecture in Sect. 2, the paper proposes to review existing standards in both civilian and defense automation in Sect. 3. The existing standards regarding land vehicles automation may be fundamentally divided in two types: architecture driven (AUTOSAR, GVA, JAUS, ROS) or functional safety requirements (ISO26262, or its counterpart in aerospace, the DO178). The impact of a decisional architecture for autonomous driven is discussed throughout a critical analysis in Sect. 4.

2 Layered Decision Making

2.1 Motivation

Automated driving is a global target, gathering different functional levels (see Fig. 2), that should be introduced step by step, according to the current legal framework, market and technology maturity [2].

Currently the most advanced automated driving level allowed by legal framework is Level 2. It includes temporary longitudinal and lateral control of the vehicle based on sensors and software logic. Although the vehicle is driven automatically the driver shall permanently supervise the good operation of the system and be in position to take immediate control if required [2].

Higher level of automation (Level 3 of automation or Conditional Automation) is currently being developed in order to further improve road safety, and driving comfort. For instance, in some situations, the automation can help the driving in demanding tasks like in a traffic jam or in monotonous tasks like in a long journey drive in a motorway. These functions are highly expected by end user.

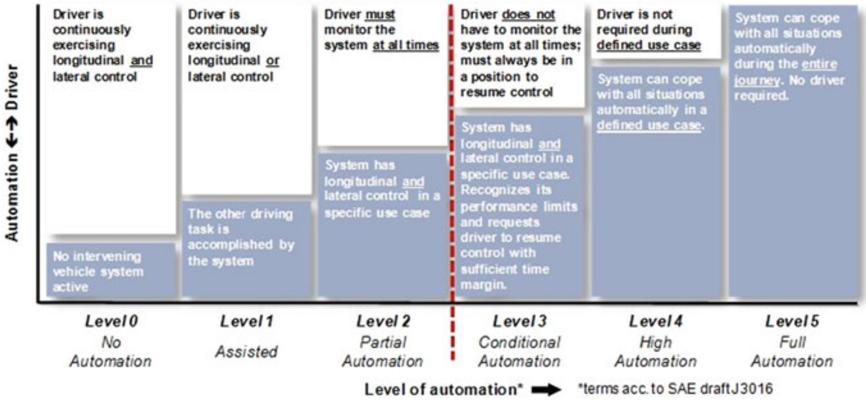


Fig. 2 Automated driving levels

For the highest levels of Automation (Levels 4/5 or High/Full Automation), vehicle management needs to tackle different levels of situational awareness. At one extreme, localisation and real-time mapping of the proximal environment is required for fine manoeuvre. At the other extreme, the global traffic conditions are required to assess mission or journey feasibility. This enables a complete awareness of the situation that can be provided to other decision making and control components.

Most of the technologies are available to construct a situational awareness either for the proximal environment or for the global mission. Indeed, the vehicle and driver have access today to networking resources that enhance the knowledge about events (e.g. road blocks) that may affect the global mission.

2.2 Layered Planning Architecture

Due to the different problem scales, multiple planning levels are necessary to guarantee a consistent autonomous behaviour. The upper level of the planning deals with long term environment conditions and mission objectives. The lower level manages short term contingencies and local driving objectives (See [10, 11] for applications in aerospace autonomy). An intermediate level deals with routes and navigability. In this approach, each level has the ability to solve a planning problem at a given scale.

3 Standardization Efforts

3.1 Generic Vehicle Architecture (GVA)

GVA is an initiative from the UK MoD to standardize the architecture of military vehicles in order to reduce the total cost of ownership of a vehicle [12]. It includes maintenance, vehicle upgrades and evolutions, in order to take into account the vehicle heterogeneity. The key main principles or properties of the architecture are the following:

- Architecture is open, and can use of third-party software
- Scalability: considering the number and variety of equipment's connected to the vehicle bus
- Modularity: new sensors or even new services shall be easily added
- Reduction of integrations costs

The scope of the GVA is to standardize electrical; mechanical; human-machine and software interfaces. The overall architecture is structured around an independent communication bus for meta-information. The modularity of the architecture is based on a Service Oriented Architecture (SOA) approach. The architecture consists of several communication buses off different levels:

- 802.3 Ethernet bus for best effort traffic
- Time trigger Ethernet for deterministic traffic,
- MILCAN bus
- Energy bus
- Software bus based on the Data Distribution Service middleware (DDS) and the GVA data model (Land data model)
- Video bus based the PLEVID standard (video over IP)

End users equipment can also be connected through USB.

The middleware DDS is based on the Publish/Subscribe paradigm. Compared to others middleware, there is no point of failure and the transport layer is highly configurable. The weakness of DDS is that it covers only the transport layer.

There is no dedicated document to describe Safety requirements, but this class of properties is addressed in the system engineering method. Nevertheless, Health and Usage Monitoring of automation System techniques contribute to the safety of the overall system.

3.2 JAUS Standardisation

The Joint Architecture for Unmanned Systems (JAUS) standardisation process comprises a set of standards focusing on both system and operational independence of the robot [8]. JAUS comprises different sets of models, architecture designs, requirements and interfaces at vehicle, mission and systems levels. JAUS can be seen as a layered standard:

- Capabilities from the mission/user: JAUS SAE AIR 5665 provides an Architecture Framework for Unmanned Systems,
- Application level interfaces: SAE AS 5710 and SAE AS 6009 define those interfaces with unmanned system components.
- The JAUS Service Interface Definition Language (JSIDL, SAE AS 5684).
- The Link Layer level, JAUS Transport Specification (SAE AS 5669) defines transmission protocol over standard networks.
- Other JAUS standardisation processes define ontologies for architecture design (JAUS Service Interface Definition Language) and components as well as reference architecture (SAE Aerospace Information Report AIR5315—Generic Open Architecture GOA).

In JAUS, both safety and decision making requirements are not fully addressed and it is not possible to guarantee the vehicle autonomy behaviour. The JAUS standardisation process is not very active.

3.3 AUTOSAR

The increasing evolution of the vehicle applications leads automotive systems to a high level of complexity. In order to manage this issue, a development partnership of automotive manufacturers, suppliers and tool vendors has been organised to develop the Automotive Open System Architecture [6]. AUTOSAR objective is to create and establish an open and standardized automotive software architecture whose main goals are:

- Scalability to different vehicle and platform variants
- Transferability of software throughout network
- Support of different functional domains
- Increased use of COTS products
- Integration of different modules from multiple suppliers
- Support of applicable automotive international standards and state-of-the-art technologies
- Safety mechanisms considerations as well as dependability

To improve cost-efficiency and reusability, AUTOSAR separates application software from the associated hardware.

To achieve the technical goals of modularity, scalability, transferability and re-usability of functions, AUTOSAR provides a common software infrastructure for automotive systems of all vehicle domains based on standardized interfaces for the different layers as shown in the Fig. 3.

AUTOSAR basic concepts are:

- Standardization of the interfaces, application software components description, basic software and hardware abstraction layers
- Description of system and processing constraints
- Virtual functional bus which contains all communication mechanism and interfaces
- Functional mapping over processing resources and generation of their associated runtime environment and basic software configuration

AUTOSAR supports ISO 26262 standard and offers various safety mechanisms such as:

- End to end protection to ensure integrity of data transmitted through communication links
- Memory partitioning to prevent software components from interferences between them
- Basic software module defense behaviour to prevent from unauthorized service calls
- On-line Program flow monitoring to check correct software execution sequences
- Timing determinism/protection
- Dual microcontroller architecture

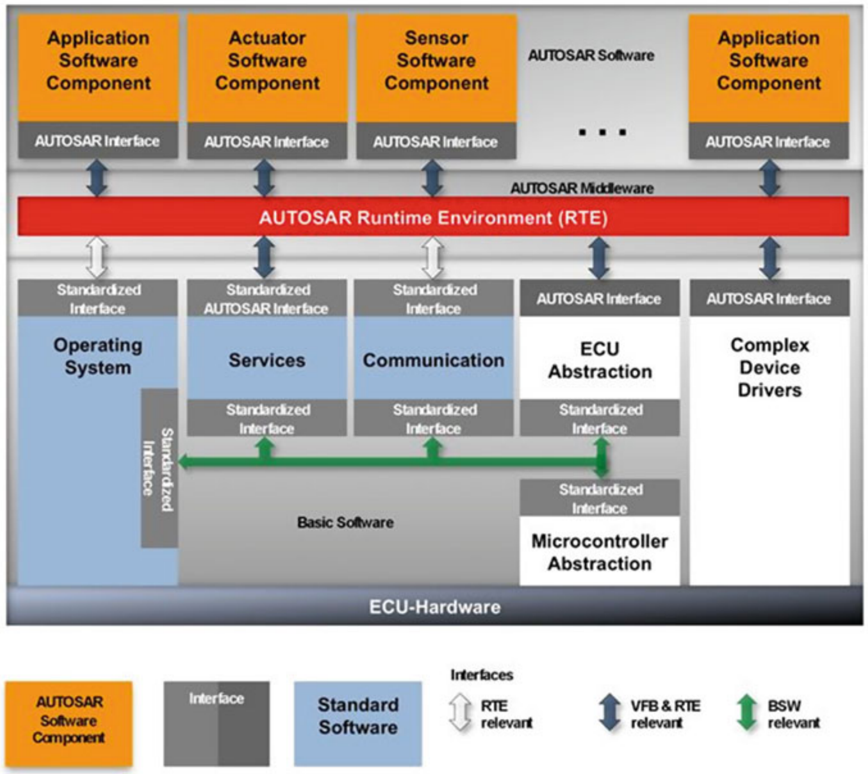


Fig. 3 AUTOSAR architecture

AUTOSAR combines the interest of an architecture description language (ADL) with partition-based execution, such as the ARINC 653 in aeronautic.

3.4 ROS

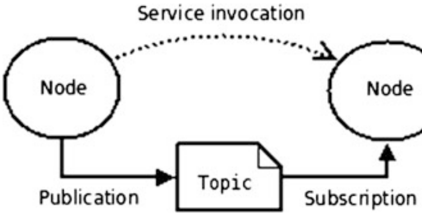
The Robot Operating System (ROS) is an open source distributed robotics platform designed to accelerate robotics research and development, including commercial application development. ROS is a high-quality, actively maintained, well-documented software platform intended to support the academic and industrial robotics communities. ROS includes reusable components that implement a variety of low- and high-level functionality, such as base navigation, mapping, visual odometry, arm planning and control, data visualization, object recognition, and task-level execution. ROS supports a number of research robots and common robot simulators.

All ROS software is released under an Open Source license, and the great majority of it is licensed under a BSD-style license that allows users and companies to build applications on top without licensing constraints.

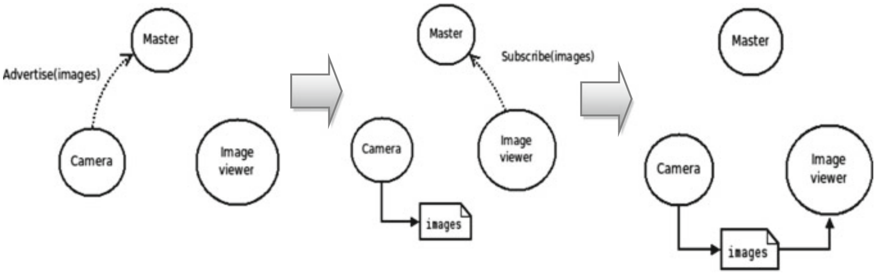
ROS has three levels of concepts: the Filesystem level, the Computation Graph level, and the Community level.

The Filesystem level concepts are ROS resources that you encounter on disk, such as Packages, Manifests, Stacks, Stack Manifests, Message Types and Service Types.

The Computation Graph is the peer-to-peer network of ROS processes that are processing data together. The basic Computation Graph concepts of ROS are Nodes, Master, Parameter Server, Messages, Services, Topics, and Bags, all of which provide data to the Graph in different ways. These concepts are implemented in the ros_comm stack.



Example of an "images" topic publisher/subscriber procedure using the ROS Master registration.



The ROS Community Level concepts are ROS resources that enable separate communities to exchange software and knowledge. These resources include Distributions, Repositories, ROS Wiki, Bug Ticket System, Mailing Lists, ROS Answers, and Blog.

Open topics like the support for fail-operational execution with dependable communication and firm real-time execution, model-driven development, quality management, safety qualification, cross-platform portability, and joint industrial

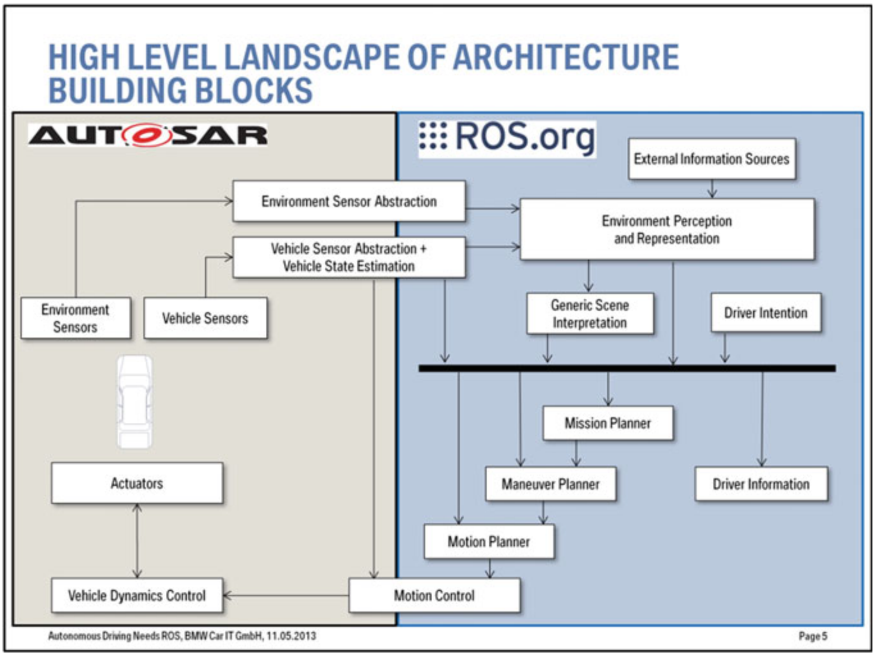


Fig. 4 BMW architectural building blocks for autonomous driving

roadmap for development are already being addressed by the large ROS community, ROS for Products and Industrial ROS.

The following Fig. 4 by BMW Car IT GmbH shows the architectural building blocks for autonomous driving and how they could be distributed among the two frameworks, AUTOSAR and ROS.

4 Critical Analysis

4.1 Towards a Decisional Architecture Standard?

Several architectures have been specially designed and implemented to control autonomous road vehicles. A huge variety of functional decisional components has been proposed and demonstrated. Many of these architectures are often associated to a given development platform, lack maintenance and have little or no contribution to existing standards.

Indeed very few architectures have reached an industrial stage and no common design patterns for both functions and interfaces were established as an undeniable standard.

4.2 System Properties and Problems

The vehicle middleware has to guarantee the following properties:

- The safety property corresponds to the expectation that a system does not, under defined conditions, lead to a state in which human life or the environment is endangered
- The liveness property ensures that at some time the execution of a given tasks starts, progresses or ends
- The timeliness property adds timing requirements to the delivery of messages (latencies, delays, deadlines)

Today, most middleware, including DDS, do not address all these properties in a certifiable manner. Other drawback is that middleware's focus only on one layer (transport or just over the transport layer), the links with the lower layers are not specified (for instance MAC Layer or Service Admission). The list of problems to be resolved and for which it is necessary to prove the behaviour according to properties includes:

- Concurrency control algorithms, designed so as to run asynchronously over any number of processors; in spite of occurrence of partial failures at run-time.
- Synchronization of replicated processes whenever some failure occurs.
- Real-time process scheduling, where tasks that are subject to activation models and worst case execution time must fulfill deadlines.

These problems are amplified by decision making tasks (situation awareness, planning), which involve asynchronous data accesses and for which execution time are difficult to predict.

Not too surprisingly, current standardization of the state-of-the-art regarding these issues is limited. In most of autonomous architectures, these problems are related and addressed at the application layer and no generic design patterns have been proposed.

Concerning the ISO26262, the certification process can impose these properties. In general, those properties are defined by the client, which is validated using compliance tests. Some solutions are already proposed by providers, in general following AUTOSAR architecture standards.

4.3 Algorithm Complexity, Completeness and Determinism

One of the major problems is to bound execution time of the various tasks running in the systems. This is required for schedulability analysis such with ADL, or in some case to prove other system properties. Introducing situation awareness and planning algorithms lead to Non-Polynomial complexity. The designer must face the following paradigm:

Table 1 Standards comparison

	Type	Difficulties
GVA /DDS	Architecture driven	Autonomy/safety
JAUS	Architecture driven	Decision making/safety; deprecated
AUTOSAR	Architecture driven	Decision making
ROS	Middleware	Safety/portability
ISO 26262	Requirements driven	Autonomous systems complexity

- Non complete polynomial heuristic may be proposed, but the system may not provide a solution corresponding to the operational situation.
- Complete algorithms are proposed, but since they process tree search, it is difficult to provide deterministic delays (although, in some case, the operational semantic of the algorithm can be deterministic).

These problems have never been addressed in any standards able to deal with autonomous systems.

4.4 A New Systems Engineering Domain?

Each standard has its own scope and drawbacks and evolves in its own direction. No standard completely covers the domain. For an architecture driven approach, the standardization process must consider all relevant design patterns from the state of art in autonomous systems, for example the ones quoted in the paper. For a requirement driven approach; Safety Integrity Level (SIL) should include the formulation of new properties as well as assumptions that are specific to decision making tasks.

Current standardisation approaches can be positioned in the Table 1.

5 Conclusion

This paper has provided an overview of the ability of current standards to take into account decision making architectures such as layered planning for autonomous systems (levels 4 and 5 of automation).

It seems that autonomous systems must integrate a distributed executive that would contain some of the algorithms and protocols which solve problems briefly introduced in the above. This should yield to new practices to guarantee safety of autonomous functionalities.

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Part IV
New Usage of Cars with More Automation

User Experience of Dynamic Carpooling: How to Encourage Drivers and Passengers?

L. Créno

Abstract In the “Internet world”, the car is rapidly becoming one of the most connected elements in our everyday’s life. Our research topic deals more specifically with drivers who connect their smartphones to carpool with strangers. In fact, smartphones communicate crucial data for eco-mobility, such as the number of “empty seats travelling” [1], available for potential passengers. Thanks to the GPS, 3/4G networks and “dynamic carpooling” applications, the car stands out as the new “public-private” transport. This innovative service of dynamic carpooling develops in a lightning way. In this article, we decided to present a state of the art, which details successively the history of the practice, the technical components of the service, the issues and needs for a sufficient critical mass of users, the benefits and limits of the system. Then, we describe various examples of incentives, updated during the deployment of large-scale studies to encourage the practice to a larger number of users.

Keywords Dynamic carpooling · State-of-the art · Critical mass · Benefits and limits · Incentives

1 Introduction

Studying new mobility services is an important environmental, political and social issue to deal with the urgency to decrease pollution and congestion within our cities. Carpooling in particular, allowing “*the common use of a vehicle by a not professional driver and one (or several) passengers with the aim of making all (or part) of a common route*” [2], is shown as an interesting solution to reduce the

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number of vehicles in circulation therefore the greenhouse gas emissions [3]. From this general definition and depending on the organization chosen by users, carpooling can take two main forms: it can be planned or dynamic.

1.1 From Planned Carpooling

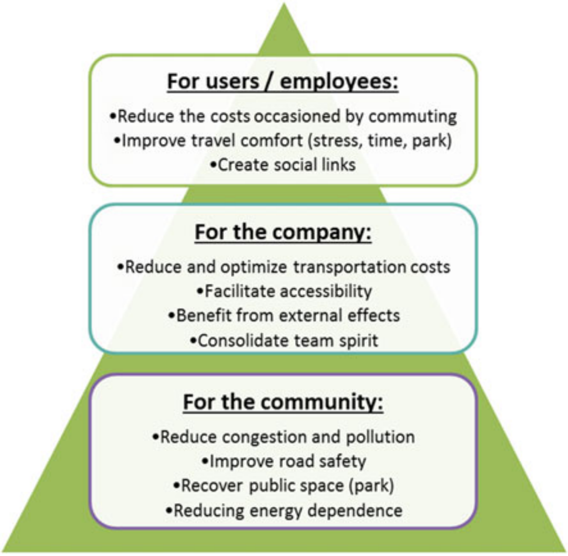
Nowadays, planned carpooling is the most widespread mobility shared practice in France. Drivers and passengers can offer and search for journeys through one of the several medium available. After finding a match, they contact each other to arrange ride's details: Costs, meeting points, luggage space… Then, carpoolers meet and carry out their shared car journey as planned.

The Fig. 1 presents the planned carpooling advantages for the users/employees, company and community:

However, there are still various drawbacks:

- Loss of flexibility and deprivation of liberty in relation to an individual car using mode [2, 4–6].
- Necessity to plan and organise in advance the journey: destination, travel time, luggage volume and other organisational elements. It creates a sense of dependency to one another [4, 7].
- Detours to retrieve drivers may hinder the practice, loss of time [8].
- Parking difficulties: parking space is not always available at the point of rendez-vous.

Fig. 1 Planned carpooling benefits of [2]



- Financial transaction: the amount of compensation is another source of concern; all participants must find an economic interest in sharing their journey through the platform.
- Perceived users' risks: fear of the "unknown", carpoolers related to the relational, organisational, road risks [9, 10] or related to the lack of privacy in a shared vehicle [7, 11]. To deal with these perceived risks, which are significant barriers in the case of first uses, carpoolers try to build a feeling of trust in the service and in the other participants of the ride.

In our studies about the practice of carpooling[1] [10], we are interested in the process of interpersonal trust building. This feeling has already been highlighted as a key factor in carpooling practice [7, 12, 13]: would the person be a good driver? Would he/she be pleasant or aggressive? Would he/she be reliable and on time? Some services/websites base their communications strategy on organisational and individual online factors, which are supposed to create a feeling of trust, trying to reassure—in different ways—users about the carpooling risks (see Trustman and Dream model, from BlaBlaCar).

Some leaders of planned carpooling structure: French and European markets (BlaBlaCar, Carpooling, Liftshare, etc.) gathered about 20 million European users. Government incentives, the development of the daily carpooling between home and work, or other forms of carpooling are expected to release the practice from their marginal existence (about 3 % in France).

1.2 To Dynamic Carpooling

Along with the development of planned carpooling and to overcome the disadvantages discussed above, in France and in the world, we observe the deployment of an innovative service, perceived as the "digital" evolution of planned carpooling: the real time or dynamic carpooling. This service takes advantage of a recent and increasing adoption of internet connected geo-aware mobile devises for enabling impromptu trip opportunities. Passengers request trips directly on the street and can find a suitable ride in just few minutes. This mode of travel is in turmoil, there are now several available services which propose different usage (from the dynamic carpooling for night or cultural events, to the home-to-work journey road).

The objective of this paper is to present the results of the state-of-the-art conducted on this new way of sharing a vehicle. By describing the different methodologies and studies implemented to test the dynamic carpooling, we will try to detail: the history of this practice, the technical components of such a system, and the benefits and limitations of the existing services.

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[1] These studies are carried out within the framework of a thesis in ergonomic psychology, funded and supported by the VeDeCoM French Institute, supervised by B. Cahour and C. Licoppe, from Telecom ParisTech.

The questions we want to answer are: "What are the conditions encouraging the practice of dynamic ride-sharing? What are the brakes and levers of this innovative practice?".

We will see the methodological limitations of these studies and will emphasise the empirical difficulties restricting the records of actual usage. We will then open a discussion with some recommendations in developing better user oriented studies.

2 Materials and Methods

2.1 A Difficult Assessment of Usage

The practice of planned carpooling and more importantly of dynamic carpooling, is difficult to quantify and measure [2]. There are two main reasons for this.

Firstly: Firms and companies are used to deliver the number of carpoolers who are registered on their services and not the number of real users, who regularly carpool (they protect themselves from competition).

Secondly: Carpooling often becomes informal, users organise their rides outside platforms, thus, they are not included as real users.

To overcome these limits of quantification of usage and to further deepen our understanding about actual issues in dynamic carpooling, existing usage and available incentives to develop the practice, we will present the results of our state-of-the-art [14].

2.2 USA and Europe First Experiments to Test the Feasibility of Published Services

Initial experiments were launched from 2004 to 2012, in United States, Netherlands, Germany and Switzerland, through services like GoLoco, EasyRider, eNotion, Ridenow and Carlos. During deployment, the following problems were identified: no real-time matching, limited use in the home-airport area, lack of funding, lack of convinced partner. Accounting of actual usage is rarely available in the reports, but the experiments enable to identify difficulties and benefits of new services.

Then, experiments were conducted in France, through various forms, checking several hypotheses that included: creating specific carpool lines when passengers are informed of driver's arrival by SMS (Ecopoll Project, Grenoble); "clouds" of car sharers/carpoolers matching, but not in a dynamic way (project Carpuce, Velizy). There were about a dozen of stopped experiments in France; testing the services, the main problem was again the lack of dynamism. We will develop further the technical difficulties.

2.3 Servicing, Experiments and Wider Deployments in Progress

Our state-of-the-art has also led us to explore documents reflecting most recent successful experiments. In particular, we identify two experiments conducted on a large scale in Isère (Ecovoiturage phases 1 and 2, in 2009 and 2012) [15] by the Isère's General Council and Covivo. Within the same application, the service offered planned and dynamic carpooling. These studies have offered many results and allowed us to draw several conclusions for improving the practice. We will detail this in the next section.

Innovative services are deploying now in France, trying to offer dynamic carpooling to specific communities, in order to concentrate offers and requests to users in a same geographical area. For example, Sharette and their willingness to integrate dynamic ride-sharing in a multimodal platform, defining carpooling as new transit experiments currently favor the campus. We Drive is another kind of service which offers dynamic carpooling for commuting. The special feature is that users indicate the small community of drivers and passengers, their routes and working hours, upstream in the application. They have the opportunity at any time to notify the rescheduling of departure to the whole community, which then suggests other possible matching (back guarantee by booking 2 for carpoolers by car in case of cancellation).

Finally, in USA, Ireland, Switzerland, other kinds of platforms and services of dynamic carpooling are developed. In order to reach a critical mass of users, in this case, drivers are encouraged to meet the demands of passengers who are on their way. To create a sufficient geographical network of supply and demand, the platforms establish incentives for drivers and keep the system of cost-sharing trips for the passenger. In France, this kind of dynamic carpooling is deployed in urban areas, to overcome the weaknesses of transport, especially during the evening and the night (e.g. Djump, Heetch, Miinute).

Each of these various types of services wants to popularise the dynamic carpooling and to identify the necessary incentives to guarantee a safe and effective practice.

2.4 Lessons Can Be Difficult to Capitalise

Among the studies on dynamic carpooling, we found large variabilities regarding the methods used for testing services (see also: Acody, Wallonia, Hirondo, Berkeley, Virginia Tech, pooll). We have found some measures of use, questionnaires, interviews, focus groups; conducted with various samples (from 10 to 1378 people, representative or not); covering different objectives and dimensions of the practice.

3 Results

The state-of-the-art presents successively the history of this innovative service, the requirements for its development, the main actors promoting tools and services, the current available applications of dynamic carpooling and finally incentives to achieve significant benefits for the preservation of the environment.

3.1 History of this Dynamic Way of Sharing a Vehicle

In a "Empty Seats Travelling" article from 2009, two researchers from "Nokia Research" [1] imagined a dynamic car sharing service, based on mobile phone technology and geolocation, which would not require users to organise themselves hours before hand. The idea of this service comes from their evaluation of the number and value of empty car seats in the world. With over 500 million cars, which travel nearly 5000 billion kilometers per year, filling the car from 2 to 5 cents the kilometer per seat, Nokia estimates that the value of "empty seats" would be about 500 billion euros. In the principle of this innovative service, all vehicles registered on the platform would be localised and could be prevented in real time if a passenger is waiting near a transport to go in the same direction. As a result, the preamble of dynamic carpooling was born…

As we will present later, actually several services implement this idea. The following section describes the various components of the system and current technical difficulties.

3.2 The Technical Components of Dynamic Carpooling

It is the combination of technological concepts which makes the complexity and originality of dynamic carpooling system. Below, the various components of current applications:

- Real-time geolocation of drivers and passengers (logged into the platform) thanks to the GPS system installed on their smartphone
- Dynamic treatments of carpooling offers and requests, sent from smartphones (or other connected terminal), managed from the server
- Dynamic allocation taking into account the current traffic of cars in urban area as well as cars which have not yet begun their ride through the server
- Managing allocation constraints (capacity of the vehicle versus number of passengers, date and time of the request versus date and time of the offer of carpooling, specificity of the driver ride versus need of the passenger…) to avoid conflict with the server

- Some applications contain a static module able to manage offers and demands for planned carpooling
- Payment of the ride is also automated. Some Smartphones are equipped with remote data exchange, such as NFC readers or RFID tools. The passenger can pay the ride directly into the driver account via a platform of payment.

But this combination of technology is not enough, it is then necessary to create a sufficient critical mass of users to keep an efficient running of the platform.

3.3 The Keystone of This System: The Development of a Critical Mass

The immediacy and flexibility of dynamic carpooling is based on the hypothesis of a large network of drivers and passengers, located in a same geographical area, at the same time. Thus, the service must accumulate a critical mass of users, large enough to cover each driver's proposal and passengers' request, in a very short time, in a specific geographical area. The sustainability of the practice depends on the real-time matching of drivers and passengers.

To date, there is no standard ratio "number of users per square mile" which guarantees an efficient dynamic ridesharing. An in-depth study in Isère in 2010 [15], involved an estimated potential of 4,500 rides and 4,500 return rides/day on 2 thorough fares targeted. The study finally recognizes 488 people registered for the service and observes the realisation of 375 carpooling for a period of 10 weeks; then, 10 % of the offers triggered an effective carpooling.

The CERTU [2] describes that indicative mass of users should not be less than 1,000 people, if the service develops on a specific urban axe/area. In terms of market place, it is the large living areas or localised generators of travel zones (universities, businesses) that are the most conducive to the establishment of a dynamic carpooling practice.

Benefits and incentives developed in the next sections should facilitate the development of this critical mass.

3.4 Benefits and Limitations of the System

But before doing so, here are the benefits and limitations of the service.

3.4.1 Users' Benefits

The first benefits offered by the dynamic carpooling is its flexible nature: the user can indeed carpool according to his desire, without planning, launching its real-time demand and getting a relevant response in a very short time, thanks to geographic location [16]. Its other advantages are the absence of such a constraint with the crew; users are not required to prevent others with schedule changes; they cannot ask for significant detours because the system matches precisely their ride. Oliphant and Amey [17] and CERTU [2] also show that the participants cooperate to save time, optimise their travel together, benefit and contribute to decongestion phenomena.

3.4.2 Users' Limitations

New users are faced with many technical bugs; they can be very discouraged by the use of the service and after suffering one failure to connect or to make an online payment, some of them quickly terminate their emerging practice. The Covivo report [15] called it: "The adverse effects of the accumulation of technical failures" and explained this was the main source of criticism and lack of motivation. Also, at the launch of the service, it is important to ensure: a high reactivity in the information about the source of the problem and its resolution; regular adjustments during testing; a good use of the tools and familiarity with the mobile application.

According to Girard [2], the practice of carpooling must be democratised before the dynamic tools find their place in the ecosystem of mobility services. In terms of governance, it is necessary that dynamic carpooling is organised and implemented at an appropriate institutional level. Data must be interoperable to aggregate databases and achieve sufficient critical mass.

3.5 Incentive Measures for the Development of Dynamic Carpooling

To collect a sufficient critical mass of users and enable a fluid use of dynamic carpooling, according to our reading, here are some incentive measures which should be taken into account:

- Define a geographical coverage area of the service: selecting for example large living areas of universities, administrations, companies;
- Mutualize existing platforms of carpooling including planned and dynamic services of carpooling;
- Communicate widely about the development of this innovative service;
- Ensure confidentiality and data security/traceability for drivers and passengers (with voice recognition systems, or GPS tracking);
- Define and integrate services of dynamic carpooling in programs laws, as it was done for planned carpooling. This will encourage the cooperative development of secure platforms and the users to experience the tool;

- Optimise matching in a technical point of view. Developers of carpooling are constantly seeking to improve the accuracy of real time matching, taking into account the detours and algorithms;
- Build partnerships with other mobility systems (taxi fleets, carsharing, public transport shuttles) to offer carpoolers an assurance on return.

From the perspective of usage, to create trust in the service, limiting the "fear of the unknown" and to facilitate the process building of interpersonal trust, dynamic carpooling must:

- Secure financial transactions. Depending on the business model chosen by the operator of dynamic carpooling, the rate per reservation can be charged, and the cost per passenger may be fixed by dividing the total cost of the trip by the number of passengers in the car. Alternatively, the cost per passenger can be variable, depending on the number of kilometers actually carried out by each of them (vast majority of services).
- Create a "tribe effect" [2] to avoid the "dissuasive unknown". It is necessary to design trust communities, involving individuals around the web 2.0, which promotes interactions between users and the creation of social links (see GoLoco). Dynamic carpooling and this kind of platforms offers various contents of users' profiles (with objective and subjective factors about drivers and passengers), serious ways of controlling a new driver in the community, etc. Communities can take different forms and rely on social networks, professional, or special events. The carpoolers' online profile allow the cross and the multiplication of drivers/passengers information, which means that nobody stay a "stranger". Moreover, people in the same company or university, sharing information, can share the same specific cultures and historical modes, so they can be places for the development of trust in carpooling practices [7]. Gruebele [18] for the rapid development of the service, highlights the importance of common and shared stories in order to develop positive relationships: "*Creating a group whose members have similar interests will tend to make the group more attractive, and emphasizing to group members their unique skills or knowledge will tend to make them believe their efforts matter*" [19]. Resnick [16] even purposes to users to be matched with others thanks to their personal criteria (social, ethical or religious backgrounds). Allowing matching on personal and intimate social criteria, carpooling will become a social mobility experience and will deviates from the traditional model of transportation of anonymous people. This raises the question of the means necessary to reassure the user before testing the service.

Finally, it is recommended to encourage users to sustain their practice through:

- Financial incentives: tax incentives/tax breaks/modulation or free of taxes/insurance premiums/discounts on parking fees/vouchers. It means find winning formulas for carpoolers to encourage their sustainable practice [20];

- Reassuring infrastructure: Areas of carpooling/HOV lanes/reservation of spaces in parking. The issue of opening or booking special lanes for vehicles with high occupancy rates (carpoolers) means a systematic identification and control of people in the cars. For Kelley [21], significant economic investments to build lanes might be replaced by individual grants for users.

4 Discussion

The objective of this paper was to present a state-of-the-art on the practice of dynamic carpooling. We pointed the complementarities and features of dynamic carpooling with planned carpooling. As we noticed, one of the current challenges in dynamic carpooling is the creation of a sufficient critical mass of users. It requires overcoming various issues: the lack of supply and demand in one place and at the same time, the fear of this new service and of the matching with an "unknown" person, the technical bugs and the lack of driver guarantee.

We then presented the benefits and limitations of the service. Previous studies have adequately identified incentives which can increase the usage. However, it lacks experiments focused on real user experience to understand the brakes that occur "before, during and after" these shared mobility experiences. The idea is then to advise platforms and users to how purpose or get a positive, sustainable and trustworthy practice. In this sense, we initiated a study with users of a service of urban dynamic carpooling in the Paris region. We gathered drivers and passengers situated data, thanks to observations in natural situations and in-depth interviews. Once the data will be processed, our goal is to propose several recommendations to encourage and improve the system.

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Decarbonated and Autonomous Vehicles: The Relevant Legal Consensus

Yvon Martinet

Abstract Legal considerations have to be taken into account in the development of new technologies that concern safety, security and more general the society. This article describes the legal framework from different angles including product liability and criminal with a particular attention on the Vienna convention, French law and international evolutions.

1 Introduction

The implementation of pending decarbonated and autonomous vehicles projects may take into account a progressive evolution of the legal framework.

However, the pending instruments (at the national, regional or international levels) are flexible enough to implement immediately a legal consensus practicable over the operational projects, through the international or national legal grounds.

2 The Vienna Convention and the Definition of "Driver"

Most of European countries are bound by **The Vienna Convention on road traffic** adopted in 1968 whose articles 8 and 13 provide that:

> "Article 8. Drivers
>
> 1. Every moving vehicle or combination of vehicles shall have a driver. (…)
> 3. Every driver shall possess the necessary physical and mental ability and be in a fit physical and mental condition to drive.

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> 4. Every driver of a power-driven vehicle shall possess the knowledge and skill necessary for driving the vehicle (…)
> 5. Every driver shall at all times be able to control his vehicle or to guide his animals."

> "Article 13 Speed and distance between vehicles
>
> 1. Every driver shall in any circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all maneuvers required of him (…)."

Those provisions should be read in accordance with the Vienna Convention on the law of treaties according to which "*A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.*" (Article 31)

As a consequence, Article 8 and 13 of the Vienna Convention should be interpreted in the light of technology innovation and road safety, and thus should be compatible with more automation.

Regarding French law, Article R412-6 of the Highway Code provides:

> Every driver must stay constantly in a state and in a position of performing easily and without delay all the maneuvers incumbent on him.

The expressions, "*status and position*" and "*easily and without delay*", of the Article R412-6 are more accurate than those of the Vienna Convention. The execution of maneuvers "*without delay*" involve an instant reaction of the driver to a given situation, but also the immediate deactivation of the autonomous mode.

The definition of "driver" provided by the Vienna Convention and the Highway Code does not exclude the possibility of a Supervisor being qualified as the driver, even if he isn't behind the wheel, as long as he can supervise the driving system and can deactivate the autonomous mode at all time.

In March 2014, during the session of the Working Party on Road Traffic Safety various amendments to Article 8 and Article 39 of 1968 Convention on Road Traffic were proposed by Germany, France, Italy, Austria, Belgium, in order to authorize Advance Driver Assistance Systems (ADAS), but the hypothesis of a full autonomy was not considered. The amendment on Article 8 covers the "*Vehicle systems which influence the way vehicles are driven*" and could thus include automation systems. Under this amendment, any system that can be overridden or switched off by the driver would be compatible with the Vienna Convention.

According to the estimated planning of the adoption process, the entry into force of the amendments would occur at Mid-2016.

3 Liability Issues

Today, many questions remain regarding liabilities. Existing liability systems could be applied by the courts to autonomous vehicles. However, it would probably raise questions about the definition of Driver and its obligations. Thus, in order to strengthen legal certainty, it would be useful to determine the acceptable levels of autonomy and the subsequent acceptable behavior of the driver.

3.1 Product Liability (Article 1386-3 of the French Civil Code)

The Supreme Court has already had the occasion to decide that a vehicle is a product included within the scope of Product liability. In this context, the producer may be liable even though the vehicle has received a Community type-approval certifying its compliance with technical regulations since product liability can be found independently of any defects of the product or any fault of the producer.

The defectiveness of such a vehicle could be assessed especially by considering the safety instructions communicated to the consumer during commercialization. The defectiveness could also be sought in relation to the incompatibility of the vehicle with the information provided to consumers, particularly through advertising. The expectations created amongst consumers about the properties of the product are indeed a crucial element in the assessment of a defectiveness.

Producers should therefore take every precaution, including warnings, so that consumers can assess the vehicle's degree of security (e.g. the environment in which a vehicle may or may not run in autonomous mode) and can use the autonomous vehicle in a secure manner (e.g., ability to recognize alerts asking him to switch to manual mode).

In order to seek compensation under Product liability regulation, the victim of an accident would have to demonstrate a causal link between the failure of the autonomous vehicle and its injuries. It should be noted that by two decisions of 22 May 2008, the Supreme Court accepted the evidence of the causal link on the basis of "serious, precise and consistent" presumptions.

The manufacturer of autonomous vehicles could avoid all or part of its responsibility by invoking one of the grounds for exemption, strictly assessed by case law.

3.2 Liability for Road Traffic Accidents

Under the provisions of the Law of July 5, 1985, an autonomous vehicle could be considered as a motorized ground vehicle.

The victim of an accident that intends to invoke the liability of the driver or the custodian of an autonomous vehicle (hereafter "the Operator") will have to demonstrate that this vehicle has played a role in the accident, irrespective of the behavior of the driver.

The status of driver is in principle recognized to the person who has the vehicle under control, during the accident, regardless of whether the vehicle is in motion or stopped.

In view of case law, it may be difficult to characterize the Operator as a driver in the case of autonomous vehicles. Indeed,

- The individual who is occupying the autonomous vehicle does not act permanently on the driving controls, although in the case of a partially autonomous vehicle, he is able to do it at any time.
- In complete autonomy, the individual no longer has that possibility and may even be absent from the vehicle.

In order to resolve any uncertainty, the legislator could therefore:

- Answer the question of whether the manufacturer of the autonomous driving system can be seen as the driver of the autonomous vehicle, since it defines the parameters of the system.
- Provide exemptions if the manufacturer can demonstrate that the driver has disabled the autonomous mode to switch on the manual driving.

The obligation to compensate due to the involvement of a motorized ground vehicle in a traffic accident is incumbent to the person who creates the risk of an accident, namely the driver or the custodian. Under the law applicable, the owner of a motorized ground vehicle is deemed to have the custody of it.

Within this framework, it seems hard to argue that the owner of an autonomous vehicle has transfer the custody of it to the manufacturer of the autonomous driving system. Indeed, it could be considered that the owner of the autonomous vehicle retains the use and direction of the vehicle since he determines alone the itinerary and the destination to reach, for his own use. Moreover, it could be considered that the vehicle remains under the control of the owner as he can disable the autonomous driving system.

Thus, if an autonomous vehicle is involved in a traffic accident, the owner could be considered as custodian of the vehicle and may be liable under the law of July 5, 1985.

However, the legislator may establish a presumption of custody upon the manufacturer of the autonomous driving system.

The concept of driver seems to be an essential issue at the stage of compensation, especially to determine whether any exemption is possible.

- Indeed, if we consider that the Operator is not driver, then he could be fully compensated under the 1985 Act, even though he would have been inattentive or careless.
- On the contrary, the driver of a non-autonomous vehicle, who has committed a fault, could see his compensation reduced or deleted.

It should then be determined whether the manufacturer of the autonomous driving system can be qualified as the driver or the custodian of the vehicle. If the legislator does not take sides on this issue, it would come down to the case law to decide case by case.

These two special liability regimes could therefore, in the state of the law and jurisprudence, be articulated as follows:

- If the liability of a custodian or a driver of an autonomous vehicle is searched, he may be entitled, by a recourse action, to turn against the manufacturer of the autonomous vehicle under the regime of Product liability. In this case, the manufacturer will not be able to avoid all or part of his liability by arguing that a third party has contributed to the damage, such as the victim of the accident.
- When an autonomous vehicle is solely involved in the accident, the custodian or the driver of such vehicle may not invoke the provisions of the Act of July 5, 1985 against his insurer to get compensation of his damage. He may however turn against the manufacturer under the regime of Product liability to obtain compensation.

3.3 Criminal Law

Under the principle of personal criminal liability, the criminal liability of an individual cannot be engaged because of a third party's act.

It could then be alleged that the Operator have committed an offense (speeding, endangerment of others etc.) in manual mode or by failing to regain control of the vehicle while the situation required it or after being alerted by the vehicle.

If the Operator has to be considered liable for the offense, he could invoke a physical constraint when it can be demonstrated that the autonomous driving system has played a role in the accident and has placed him in a situation in which he could not regain the control of the vehicle.

Case law had the opportunity to judge that physical constraint is constituted by an independent event that an individual could neither foresee nor avoid. The judges have indeed considered that a failure of the speed regulator has constituted "unpredictable fortuitous and irresistible" circumstances because of the inability of the driver to turn off the system.

In autonomous driving mode, it seems therefore important to question the possibility of retaining the responsibility of the manufacturer, especially in view of Article 121-3, paragraph 3 of the Penal Code, which sets the conditions for liability of legal persons in case of unintentional offense.

4 Focus on Foreign Legal Systems

Nevada, California, Florida, the District of Columbia, and Michigan have enacted laws related to autonomous vehicles testing. Nevada was the first to pass legislation and has previously licensed Google, Audi and Continental to test autonomous vehicles on public roads.

California's legislation states that the manufacturer shall submit a financial statement reflecting a net worth at least 5 millions dollars (certificate of self-insurance).

In the United Kingdom, the testing of driverless cars with high automation regulatory is framed.

Consultation by the UK Department for Transport (DfT) is undertaking a review of the relevant legislation and regulation to see that there is a clear and appropriate regime to enable cars with advanced autonomous safety systems to be tested on British roads.

Is the Law Ready for Autonomous Cars?

Gaelle Kermorgant and Odile Siary

Abstract Autonomous driving becomes real. For the first time ever the insertion of artificial intelligence into self-propelled machines, which can now operate themselves is likely to make human being as a driver redundant. Machines have the legal status of manufactured objects or instruments, but are the legal rules applicable to objects able to capture the consequences of the machine's ability to move freely particularly? The distribution of responsibility and product liability, technical standards and obviously the insurance matter are to be shaped in this respect. Besides, a special focus shall be given on data and cyber security which need to protect data autonomy and privacy to reassure potential consumers.

1 Introduction

Autonomous cars are also called self-driving, driverless, unmanned, automated, fully automated, automated, robotic or delegated driving cars. These are vehicles able to carry out most or all of the operations of driving without the active control or continuous monitoring of a human being.

They are not commercially available on public roads yet, although a growing amount of technology is installed in cars newly introduced to the market and some completely autonomous prototypes can be seen.

Technology allowing full autonomy is ready but the few legal activities in this area are only covering the testing modalities. Four states in the USA have enacted laws authorizing autonomous cars testing and a few cities in Europe are implementing driverless cars testing under local regulation. Autonomous cars are perceived by policy makers as a desirable mean to make the roads safer and therefore less costly in terms of human lives and repair costs. The ways to tackle the legal issues generated by such a new product are under discussion. A comprehensive

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review of regulations for automated vehicles has recently been published by the UK department of transport as a result of a wide stakeholder consultation on the matter, showing the interest that regulation of autonomous cars generates.

The very first question is whether autonomous cars are legal with respect to the existing corpus of law, and how ready is the law to accommodate the introduction of this new technology at a mass consumption level. This article has a limited scope as grasping the full range of regulatory issues triggered by autonomous cars would require a much more detailed examination. So we will try to consider at a high level the main issues at stake which are the rules around the need for and the behaviour of a human driver, the distribution of responsibilities, and their financial coverage (insurance), and the possible legal issues generated by data collection, storage and use by, and through, autonomous cars.

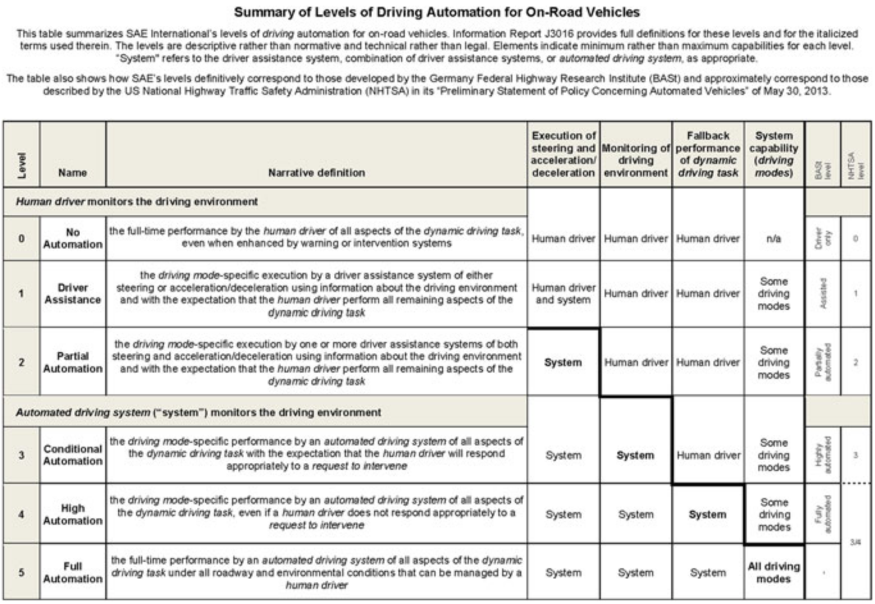
2 Autonomy Levels and the Human Driver

2.1 Vehicle Autonomy

Technical enablers like sensors are physical devices enabling the perception of the physical environment of the vehicle in order to get information about itself and its surroundings. Various kind of sensors combine to create a suite of capabilities and provide different kinds of data. Actuators are the vehicle's control units that enable the performance of physical actions. Embedded computing systems run software algorithms interpreting data provided by sensors. They "make sense of the world". Computing systems are then potentially connected with other vehicles and with external infrastructure such as the cloud. They plan action, take decisions to act and send actionable commands to the actuators. These systems enable navigation (self-localization, motion planning, motion control, obstacle avoidance) using cloud and satellite based resources, interact with human beings and enhance capabilities via machine learning. Autonomous cars are programmed with a model and can then learn and modify behaviours by themselves either within a predefined set of parameters or through free-range learning. Also, autonomous cars, as part of complex multi-agent systems through their cloud connections can access new types of collective and predictive intelligence.

Autonomous systems are joint human-machine cognitive systems and can be characterised by multiple degrees of autonomy depending on the right balance between safety and performance.

The National Highway Traffic Safety Administration (NHSTA) and the Society of Automotive Engineers (SAE) have set levels of autonomy for cars summarised in the following table (source SAE):



Summary of Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of *driving* automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

2.2 The Human Driver Requirement

Autonomous driving means less or no human driver intervention at all in the central loop to perform the function of driving. The question is whether such situation can be tackled by existing law.

Road traffic is largely regulated by international conventions. The first one, the Geneva Convention (1949) provides that all vehicles must have a driver that is able at any time to control the vehicle without actually defining further what a driver is. The Vienna Convention (1968) applies to most European Countries including Germany, France, Italy or The Netherlands, but has not been signed or ratified by countries such as the UK, Spain, the USA or China. However it elaborates further on the driver concept. Its article 8 provides that all vehicles must have a driver with physical and mental ability, being physically and mentally fit to drive and having the knowledge to drive. Article 13 adds that the driver must have the vehicle under control in all circumstances.

Indeed the writers of these Conventions never imagined that cars would be able to drive themselves so it is never specified that the driver should be a human being. A literal interpretation of this Convention could be inclusive of an electro-mechanical system as an authorized driver. Such interpretation has been put forward particularly with respect to the Geneva Convention and its application in the USA, where four states have actually allowed a test circulation of autonomous cars by enacting a specific regulation. Similarly, in the UK, the Department for transport reckons that the Vienna Convention is not considered as an obstacle. It considers that the UK has signed, but not ratified, the Convention and testing is thus consistent with proper driver control.

Countries who signed the Vienna Convention are currently discussing the addition of new provisions that would specifically allow the use of automated systems, but would still require the driver to be able to override or switch off such system. It is likely that after this amendment further changes will be needed to acknowledge the state of full automation. However, keeping the Convention as it is would have allowed a more flexible literal interpretation regarding the driver requirement because as already mentioned it is not specifically required for the driver to be a human being.

2.3 Driver's Behavior

Road traffic laws are centered on the driver. With partially automated cars, the human being is still the driver of the car but he, or she, is merely supervising a technology, ready to intervene at any moment. With highly and fully automated cars the car drives itself. The responsibility for adequate control of the car has thus shifted from the human user to the machine. The most important aim being safety, this progressive disappearance of human driver will imply further changes to the law.

On one hand manufacturers will have to ensure that cars can comply with existing road traffic laws, for instance the necessity to include into software several standardized pre-determined requirements for compliance with existing road traffic laws.

On the other hand some of road traffic laws also should be changed for autonomous cars in terms of safety distances or speed limits. Perhaps, an even higher standard of driving than expected by a human driver could be expected by law.

It is also arguably certain that in "*human out of the loop*" driving situations the responsibility for accidents will shift to the vehicle as a product and therefore to its manufacturer. In the hybrid case of partial automation, the responsibility will be distributed between the driver/operator of the autonomous car and the manufacturer but, in full autonomous mode, the responsibility for avoiding an accident will shift entirely to the vehicle and the components of its accident avoidance systems. Most important will be the transition period between human control and full automation.

3 Distribution of Responsibility

Autonomous cars are complex industrial products. They are designed, manufactured, programmed machines and, as such, comprise many different technical contributions to their overall functioning and behaviour.

3.1 Product Liability

Cars, as machines are subject to very specific regulations providing for compliance to technical standards. The applicable regulation in the European Union is the EU Machinery Directive.

Cars are also products, and as such, are regulated by the EU Product Liability Directive. Manufacturers have a strict liability for the products they put on the market. This means that the producer is liable for personal injury and property damage caused by a defect in the product, without the necessity for the claimant to demonstrate a fault. Development risk and contributory fault by the user of the product may be used for defence.

3.2 Technical Standards

Technical standards set a level playing field for cars manufacturers and a presumption of safety for cars sold on the EU market. They work in combination with the machinery and product liability directives setting the standards of safety that a person may reasonably expect. Some standardization institutions have already issued standards for automated car components by SAE and NHSTA, but not yet by the International Standardization Organisation (ISO) which is the global reference. However, further standards will arguably be issued in respect of the development of technology, whilst others will be amended.

3.3 The Issue of Distribution of Liability

Distributing proportionate responsibility between the parties responsible for designing and manufacturing the various parts of the vehicle (software, sensors, actuators), maintenance and safety contractors, traffic operators or internet services interacting with the vehicle, might prove difficult.

Pushing the thoughts even further, fully autonomous cars could in the future be adaptive through machine learning abilities. Such features will involve unpredictability in behaviour. Indeed, behaviour attributable to the program set by the programmer or the manufacturer will not entirely be planned because of the incremental experience of the vehicle itself. In this respect the fully autonomous and self-learning car will transcend the traditional legal status of cars as inanimate things, to become an artefact that has the possibility to move freely with the capacity to act and decide beyond the control of humans.

So far, however, autonomy is limited to deterministic processes. In any case, this issue needs to be kept in mind, as it is extremely important due to the potential of autonomous systems to cause or produce fatalities to human beings by making what would be perceived as “judgement calls”.

In a situation where a human is in the loop, responsibility will be distributed between the operator of the car and the manufacturer. The operator will have to be able to take over control from the car if required and could be deemed responsible in case of misjudgment of the situation by human or by car. It is obvious that the interface between human and machine must be clear and that operators will have to be trained about the functions of the vehicle to understand when they must take control of the car.

The responsibility for damages occurring in full automation mode and not attributable to a machine defect is still an area to be investigated by the law. Various solutions are being proposed. Rules of responsibility of parents for children or keepers for animals could, for instance, be used by analogy. However, setting standards for autonomous cars behaviour and their care will prove difficult, at least in a foreseeable future. Owners or users will have difficulties to understand how such complex machines are working and whether they present any dangerous tendency that is not typical of similar models.

Setting a full responsibility for manufacturers could also be considered by extending existing rules on product liability. This could however cripple commercial deployment of autonomous cars and thus limit their potential benefits to society.

From a criminal perspective it is also likely that new crimes linked to autonomous cars notably in the fields of hacking and terrorism might emerge. If new crimes are not defined, then the principle of legality of criminal law could create loopholes in the system giving immunity to criminals.

Suggestions to grant to autonomous cars and other autonomous agents a legal personality by analogy with corporations would be an inclusive legal response (it is interesting to note that the legal fiction of corporation legal personality was integrated by the law in respect of the material economic and social changes generated by the industrial revolution and the introduction of railway transport).

Insurance systems have also by all means an important role to play here.

3.4 Insurance

The EU Motor insurance directive 2009/103 provides for mandatory insurance for the use of a car. Car insurance is based on human driver capability and this well-established logic is becoming problematic in respect of autonomous cars as the risk is transferred to the machine.

Because of this risk transfer, liability will increase for manufacturers, who will have to provide for further insurance coverage in this respect.

It is said that autonomous driving will lead to less car accidents. Insurance companies need to take this evolution into account. Though insurers will require to know and understand the user habits or behaviours less, doubtlessly they will want to know more precisely the various types and models of technology embedded in the car (and above all the duration required to take control of the car), to evaluate the risk and thus to evaluate the financial hazard of such a car. Insurers will have to perform new statistics on the reliability of driving car by car, technical solution by technical solution. They will (have to) create new data bases to offer adequate premiums. This work will involve lots of investment and as a consequence a premium price reduction will not be on the agenda before years. Risk based responsibility systems already exist for cars but insurance costs are mutualised and actuarial calculations are based on the predictability of traffic accidents which is not compatible (in the near future) with the new levels of risk and unpredictability created by autonomous cars.

Insurance companies will request access to data information carried by cars. Indeed, to deal correctly with liability in case of accident, it will be necessary to obtain data recorded by the car (speed, when the car asked the human to take control of the car, etc.). Hence, it might be necessary to define clear rules for the storage of personal driver data in an event data recorder and to allow the manufacturer and the insurer to analyse this data in case of an accident.

4 Data and Cyber Security

4.1 Importance of Data for Autonomy

Acquiring information in real time is one of the keys to the success of the safe autonomous car. For vehicles to run their course with ease, they need to know, in real time, dangers of the road (e.g.: potholes), zones requiring greater vigilance (e.g.: road near a school) or unexpected road works or car accidents.

In order to perceive the environment, cars are equipped with satellite navigation systems, digital map data, on-board sensors, radar mapping and other supporting communication means.

However, as equipment is not infallible and sensors might fail, it is important that vehicles are able to compensate for missing information by communicating with each other. With this thought in mind, recently the NHTSA has imposed such equipment in the USA.

In addition, a car's own electronic control units enable software to make sense of this information. Finally event data recorders ("black boxes") are set for statistic and post control of the car actions.

4.2 A Threat to Security

Communication of data constitutes a threat for human security—which might seem paradoxical in view of its original purpose. In a nutshell, all security issues triggered by the internet would also exist in the case of vehicle communication. No matter how secured and robust the system might be, data exchange can never be trusted to be perfectly secure; therefore even the most powerful cyber-encryption scheme would fail to protect, should an attacker alter the physical measurements and therefore the input to the encryption scheme.

Security is at stake as burglars, terrorists and hackers might be able to retrieve data and destroy them. As a consequence, in addition to a highly protected infotainment system, a regular update of software in the vehicle is required to avoid malicious intrusions, as such attacks are likely to sorely undermine consumer confidence in connected cars.

4.3 A Threat to Privacy

Privacy is likely to be jeopardized by the images and data captured by various vehicles, even if the exact nature and quality of data that will be collected is yet unknown. Personal data protection and processing is provided for by two European Union directives and autonomous car should be compliant with rules.

Car manufacturers argue that to avert/circumvent prejudicial treatment of the right to privacy, data will be deleted after a relatively short time lapse. Nevertheless, since vehicles will communicate with each other and infrastructure beacons, the question may be asked, how can it be ascertained that the data will actually be erased.

It is acknowledged that legal restrictions may be imposed on the right to privacy provided that these restrictions genuinely meet objectives of general interest and that the collection of information is proportionate with its intended use and limited to that. Safety and responsibility monitoring will require that data is recorded and accessible to third parties such as insurance companies or courts. The proper balance with privacy could be anonymisation of all data processed by the car.

Car manufacturers will have to devise a standard harmonized documentation clearly informing users of the connected cars about what/which data will be collected, for what purpose, the way it will be processed and shared, when and how it will be deleted and enabling recording of consent from users.

Privacy and security by design are thus important and a new European package on data protection is being drafted that will apply to any data concerning EU resident whatever the location of the data processor or controller. As most Cloud providers are based in the USA it will be important to understand from the regulator and probably European Courts of Justice whether or not the law and practice of the

United States offers or not an adequate protection to European citizens' personal data protection.

In addition the right for third parties to access to real time data, event data recorder information will require specific regulation as we can imagine how tempting it could be for insurers or public authorities to use this data to monitor speed limit infractions, to develop better insurance policies or to sell various products or services.

5 Outlook

We are well aware that this inventory of unsolved legal issues is not exhaustive and is not enough to prepare for the fully autonomous car, but it clearly shows that the law is currently not ready.

These issues are arising naturally in all countries, and it would appear to us of good governance that at least the EU countries reflect together on a harmonized legal framework to avoid the patchwork that is gradually emerging in the United States. Given the legal areas impacted we understand that this work is difficult to organize. Nevertheless, too disparate legal regimes may hinder the emergence on the market of these cars, since manufacturers will not be able to respond to every national requirement. In addition consumers will be skeptical about the rationale for these differences, wondering whether they were due to intensive lobbying from carmakers or based on citizens safety and security. On that last point we must not forget that today the European consumers are not all geeks and those who may benefit the most by these new embedded technologies would not necessarily be able to afford automated cars. It is therefore important for the regulator to assess the best manner to introduce these products which will help to make the roads safer for reasonable costs.

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Part V
Standards, Test, Validation

Challenges and Approaches for Testing of Highly Automated Vehicles

Hans-Peter Schöner

Abstract Testing of highly automated vehicles has new challenges with respect to the questions to answer, the test cases, and the testing procedures. Main questions arise from the fact that highly automated vehicles are required to achieve high levels of availability and effectiveness of the vehicle functions; after all, their performance has to be compared to the performance of human drivers. Testing of such vehicles requires international consensus on the required level of safety and on the metrics to be applied. The main challenges for such testing are discussed and some new approaches are presented.

Keywords Testing · Highly automated vehicles · Simulation

1 Towards Highly Automated Vehicles (HAV)

In the past years, several companies and institutions have shown quite well functioning technologies for detecting the environment, algorithms for path planning and collision avoidance. On the other hand, more and more semi-automated functions are readily available in vehicles in the market place, like adaptive cruise control and lane keeping. These functions take over tasks which traditionally have been done by the driver. The driver's task is reduced to judging when to turn the system on and off, and to monitoring constantly whether the current conditions are still adequate for the function to work; but he also has to serve as a fall-back solution, when the system by itself judges that it can no longer safely manage the situation.

It seems a very small step to release the driver completely out of the vehicle control loop, at least temporarily during boring driving conditions, be it during a

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traffic jam or for continued constant speed driving on long journeys. But on closer inspection, this step entails considerable challenges.

2 Specific Challenges of HAV

In case of a take-over request in a semi-automated vehicle, the driver is required to take over vehicle control more or less instantaneously. If the driver is out of the loop in a highly automated vehicle, response times will be longer in average. Although in simulator experiments drivers respond very fast on intense take-over signals (like a warning sound with simultaneous brake impulse), response times of several seconds have to be considered in designing highly automated vehicles. This requires that any complicated traffic situation and any emergency situation during continuous highly automated driving must be handled by the vehicle itself, at least for the duration of this take-over time. 99 % is definitively not enough! Testing of highly automated vehicles means to prove that the vehicle can handle any driving situation in a sufficiently safe way by itself. In other words:

Before a highly automated vehicle will drive you anywhere, it has to prove that it does not drive you into trouble.

3 Safety Benchmark for HAV

A new technology generally does only make sense, if it is safer than the state of the art. For highway driving, which will be one of the first steps towards highly automated driving, the accident statistics is a quite clear benchmark. Table 1 shows the accident rates on the "Autobahn" in Germany for the 4 severity levels S0 (material damage only) to S3 (persons killed) [1]. Highly automated vehicles should not increase this accident rate, but rather help in reducing those rates to even smaller values.

Table 1 Accident rates on freeways in Germany [1]

Severity level	Average distance between two accidents of this level (km)	Accident rate (probability of accident per km driven)
S3	660×10^6	1.52×10^{-9}
S2	53.2×10^6	1.88×10^{-8}
S1	12.5×10^6	8.00×10^{-8}
S0	7.5×10^6	1.33×10^{-7}

4 Safety Assessment of HAV

When it comes to testing for very small occurrence rates, there is the general problem that a straight forward approach based on statistical analysis of the complete system would lead to extremely high and thus impracticable testing efforts [2]. Other systems with very high reliability requirements (aircraft control systems [3], electrical power distribution systems, etc.) are designed and certified by a functional analysis approach, essentially comprising the following steps:

- system design for fault tolerance (with self-monitoring and redundant subsystems),
- logical modelling of the fault tree of the complete system in order to calculate the failure rate from better known subsystems,
- verifying the failure rates of components,
- avoiding and assessing common mode failures of redundant functional subsystems.

This allows calculating reliability and safety of the complete system based on the proven properties of the subsystems, which are verified in component and subsystem tests. In the final stages, the complete system is tested especially in order to verify the assumptions with respect to functional redundancy, single failure detection and common mode failure rejection.

Understanding the driving task as a safety system and using analogous methods for functional analysis allows assessing the safety of highly automated vehicles.

5 Accident Types and Testing Approaches

One important step in a functional analysis of the driving task is looking at the reasons for accidents. There are several categories which lead to significantly different testing and verification tasks.

5.1 Failure of Components

Assessing the failure of components is well known in automotive industry. According to ISO 26262, ASIL (automotive safety integrity level) classes are defined which are required for certain critical parts. Typically failure rates between 10^{-8} and 10^{-7}/h are required for crucial systems. At a highway driving speed of 100 km/h this translates to distance related failure rates between 10^{-10} and 10^{-9}/km.

Designing components for this safety level is appropriate for the expected safety requirement level according to Sect. 3. There will be more components necessary with high ASIL requirements than before.

Some critical functions, such as keeping the lane after a substantial component failure, have to be designed at least for slow degradation; after the take-over time (which is an important design parameter for this purpose) the driver will have the task to bring the vehicle to a safe stop, as he has to do with conventional vehicles for similar rare, but critical cases.

Testing and verification of components does not ask for new methods. It has to verify the environmental robustness, has to inject failures to check functional redundancy, verify common cause failure rejection—to name some typical tasks.

5.2 Behaviour-Dependant Accidents

Inattentiveness, sleepiness, distraction are reasons for many accidents with human drivers. Such reasons will be surely avoided by highly automated vehicles. Inadequate speed, leaving the lane unintentionally and other accidents without outer influences are other candidates for significant reductions in highway accidents.

However, also highly automated vehicles have to detect the environment in order to act adequately in all cases. This includes knowing rules like speed limits, warning traffic signs (e.g. construction sites), but also weather conditions. Most of this information can be detected on the fly by sensors, but also by using previous knowledge (from maps or maintained online data bases serving as an additional independent detection channel) the detection rate can be significantly increased.

Testing for avoidance of behaviour-dependant accidents has to verify the detection ability for rules—through at least one channel—and the adaptation to the rules. Reliabilities in all single channels have to be assessed and an overall detection and adaptation rate has to be derived.

5.3 Deficiencies in Environment Sensing

Road, traffic and environment conditions have to be monitored constantly for safe driving. Detecting lane markings, seeing all relevant other traffic participants or other relevant objects and knowing the exact position of the vehicle with respect to a knowledge base (map) are crucial. Weather and light conditions have to be checked continuously, in order to assess whether highly automated driving is still adequate or must be suspended, i.e. the driving task should be handed over to the driver. For this end, a measure gauging the overall quality of the environment sensing should be established.

From system design aspects it is quite clear that environment sensing has to be done with several functionally redundant and technologically diverse sensors. The functional deficiencies of the different sensors have to be verified not only with respect to the failure rates, but also for common causes. As in many other safety systems, the relatively high failure rate of a single sensor allows for much shorter testing time than verifying the failure rate of the combined system in one step.

For testing of environment sensing, driving around in the world in order to experience many different environmental conditions (lighting, weather, locally different infrastructure, traffic conditions) is indispensable. Many of those conditions have been seen before during testing of semi-automated driving functions; thus typical detection rates of different sensor types are already known. From these values it can be deduced that a testing distance of around 500,000 km should be enough to both verify the sensing failure rates of the single sensors and to validate the acceptable rate of common causes.

5.4 Deficiencies in Control Algorithms

The knowledge of the environment, as detected from the sensors, has to be analysed and interpreted by algorithms in order to understand the situation and to deduce appropriate control actions. The algorithms have to cope with a multitude of different complex and critical situations. In contrast to environment detection, such situations can be simulated and don't need to be tested in real world. However, a sufficient set of real world benchmark test have to be performed under the same test conditions in order to validate the computer simulations.

Since there is a vast number of possible situations as input for the control algorithms, smart methods to search and find critical situations have to be established. As for the environment sensing, a measure gauging continuously the overall quality of the situation understanding (especially with respect to criticality awareness) and of the resulting control output must be established as well.

Prerequisite of a complete testing of algorithms is a good modelling of the sensor output generated by the combined sensor set. This model needs to reproduce the sensor output with respect to key performance indicators, like timing or stability of object tracking. These parameters of the sensor model should be taken from sensor signal monitoring during real world tests (see Sect. 5.3). The sensor model has to allow for specific fault simulation, according to failure injection of component tests.

5.5 Faulty Driver and Vehicle Interaction

Finally, there is a further reason for accidents, which had been dubbed "mode confusion" in the early days of autopilots in aircraft. It has to be guaranteed that both vehicle and driver are always aware of who controls the vehicle.

Faulty commanding of an automated system by a human operator must be avoided by sufficient plausibility checks within the system. A badly designed user interface can cause a new reason for accidents, which has to be avoided and verified.

For testing the user interface, driving simulator test are adequate, especially to check hand-over situations, and prove that the driver understands vehicle interaction even in critical situations.

6 Driving Risk Scenario

For the assessment of operational safety of automated driving, a risk scenario consisting of a complete set of traffic situations must be evaluated; these situations in total should represent any relevant condition a vehicle may experience during automatic driving. For each type of traffic situation the exposure value (how often does this situation occur) and the severity of accident (if it occurs from this situation) is estimated. Completeness should be assessed based upon the knowledge about reasons for accidents as mentioned in Sect. 5; situations with a (in comparison to other accident situations) negligible product of exposure and severity are irrelevant and can be omitted. Table 2 shows a list of situation categories and some examples.

This situation scenario should be generic for any vehicle, be it automated or driven by a human driver. It describes the driving risk scenario for the vehicles.

Table 2 Categories of traffic situations in a risk scenario, with examples for situation, exposure and severity, here for simplicity on a scale from 1 to 3

Category	Example: situation	Exposure	Severity
Continuous control	Keep vehicle in the lane, for any curve radius	3	3
Predictable end of automated driving	Planned exit of highway	3	1
Obstacles on the road	Sudden evasive manoeuver of vehicle ahead	2	3
Unexpected Infrastructure deficits	Lane marking not obvious	3	3
Traffic partner behaves “against the rules”	Vehicle ahead drives too fast	3	1
Weather-related challenges	Sudden glare from sun	3	3
Driver related misbehaviour	Driver not ready for take-over	2	2
Hardware problems	Complete sensor failure	1	3

7 Controllability

Controllability of the situation by the driver (or by a HAV, respectively) is a measure for how probably this situation in the risk scenario will lead to an accident. Some traffic situations are not easy to judge whether they are controllable or not. Examples are the lost cargo which falls from a truck just ahead, or the wrong-way driver which appears in opposite direction. In such situations human drivers and HAV face the same problem, because some physical limitations cannot be overcome.

Human ability to avoid accidents in a specific situation can be tested in a driving simulator. Figure 1 [4] shows how a criticality parameter (time to collision, TTC, at first sight of an obstacle in the lane) influences the ability to avoid an accident for a group of drivers, and how this can be improved by a warning system or by autonomous braking. A similar experiment can be made with highly automated vehicles on a test track, measuring the ability to avoid the accident statistically. This method can prove that highly automated vehicles can control a given situation better or at least as well as most human drivers, even if they cannot avoid an accident completely.

Controllability can be divided into the two steps “ability of detection” and “ability of reaction” for critical situations. This concept can help in better understanding and eliminating the deficits if controllability fails in an early design phase.

Each situation of the driving risk scenario contributes with its product of exposure E, severity S and controllability C to the overall risk R of driving: $R = \Sigma\{ES(1\text{-}C)\}$. This allows comparing the total risk of highly automated driving with the well-known statistical risk of human driving.

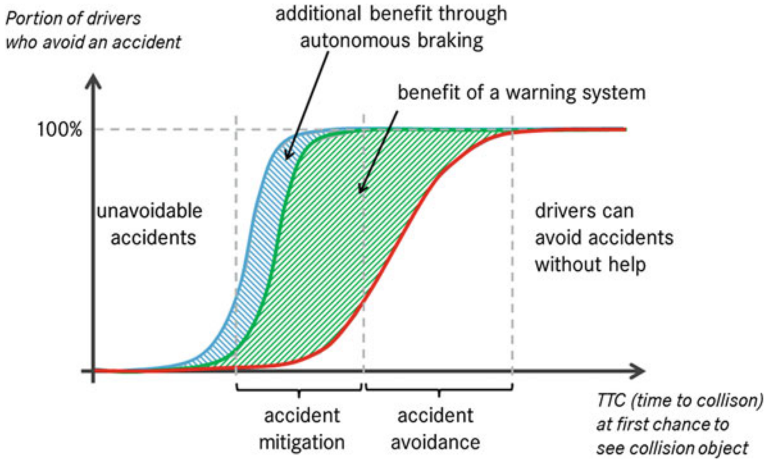

Fig. 1 Controllability of a collision situation [4]

8 Establishing Testing Standards

On national level and on the EU level, several projects will help to establish standards in testing. These projects are needed to establish a “state of the art” for verification of reliability and validation of safety of highly automated vehicles.

8.1 How Safe Is Safe Enough?

In Germany, the project “PEGASUS” (Project for establishing generally accepted scenarios and simulation methods for highly automated, cooperative vehicle functions) is in preparation, in order to define the set of traffic situations which defines the risk scenario. This should be the base for a generally accepted method to assess the safety of highly automated vehicles. The project should also define methods to measure the controllability of the different traffic situations. For situations with unavoidable accidents the project will define thresholds for a sufficiently high controllability level.

8.2 How to Validate the Safety Requirements?

“AdaptIVe—Response 4” focusses on the safety validation and technical system limits as well as on legal aspects for the introduction of automated driving.

8.3 How to Measure and Test Efficiently?

Other projects are in preparation, aiming at improving testing methods and testing automation for highly automated vehicles.

9 Conclusion

This paper describes the outline of a concept for safety assessment and testing approaches for highly automated vehicles. The work on the details of this method is still ongoing, but validated and generally accepted methods for safety assessment of highly automated vehicles will be defined within the next coming years. A world-wide consensus on such methods and testing procedures needs to be established.

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Generic Simulation and Validation Approach for Various Kind of ADAS Systems

Alfred Kless

Abstract To efficiently develop and validate such systems a generic and integrated solution providing Sensor Simulation, Virtual and Rapid Prototyping and Real Time Bypassing is needed. This paper proposes such a solution, with a comfortable editor with various predefined objects e.g. for ACC, LDW, Break-Assist, autonomous parking/driving to support easy configuration for the different validation views; access to automotive buses like CAN, CAN-FD, FlexRay, Ethernet; high speed internal access to the ECU data e.g. through Microcontrollers Data Trace Interfaces; Video Streams acquisition through various camera interfaces including Ethernet/BroadR-Reach; GPS Position data. The solution also includes a real-time bypassing and rapid prototyping execution platform. The solution works independent from the ECU supplier implementation and can be also used to compare various ECU vendors.

Keywords ADAS · Rapid prototyping · Simulation · Test · Data-Logging

1 Introduction

Precursor to autonomous drive, Advanced Driver Assistance Systems (ADAS) are getting more and more complex integrating various sensors technology (Infrared, Ultrasonic, Radar, Lidar, Camera…) with Sensor Fusion algorithm to provide functions such as Line Assistance, Side Assistance, Parking Assistance, ….

This leads to new simulation, validation and testing environment.

This paper proposes a solution to enhance the efficiency to develop and test the increasingly complexity of ADAS Systems with an integrated platform offering a comprehensive access to vehicle information, a powerful sensor simulation and a real time platform and access to the ECU.

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2 System Overview

The complete environment can be split in following parts:

- Development environment for rapidly implementing and testing multi sensor applications
- High speed ECU RAM access e.g. via Microcontroller Debug or Data Trace Interfaces
- Rapid prototyping and Real-Time Bypassing to speed up the development cycle
- ADAS ECU road validation and data logging solution with ADAS object overlay and bird view visualization.

3 CONNECT—Development Environment

Basically, CONNECT is a development environment for rapidly implementing, debugging and testing multi sensor applications. Many advanced driver assistance systems depend on reliable object detection and tracking, e.g. adaptive cruise control applications.

CONNECT provides the infrastructure to collect, record and replay sensor data and allows complex sensor data fusion applications. Comfortable visualization features enable the developer to quickly evaluate the developed prototype (Fig. 1).

Integrated into existing development environments such as Microsoft Visual Studio, enables the user an easy change-over. From the very beginning, CONNECT makes it very easy to set up an application from the scratch. The existing graphical

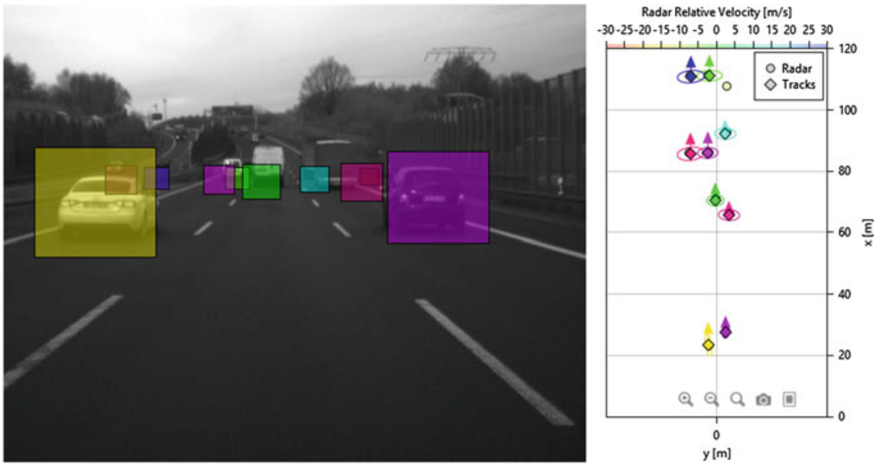


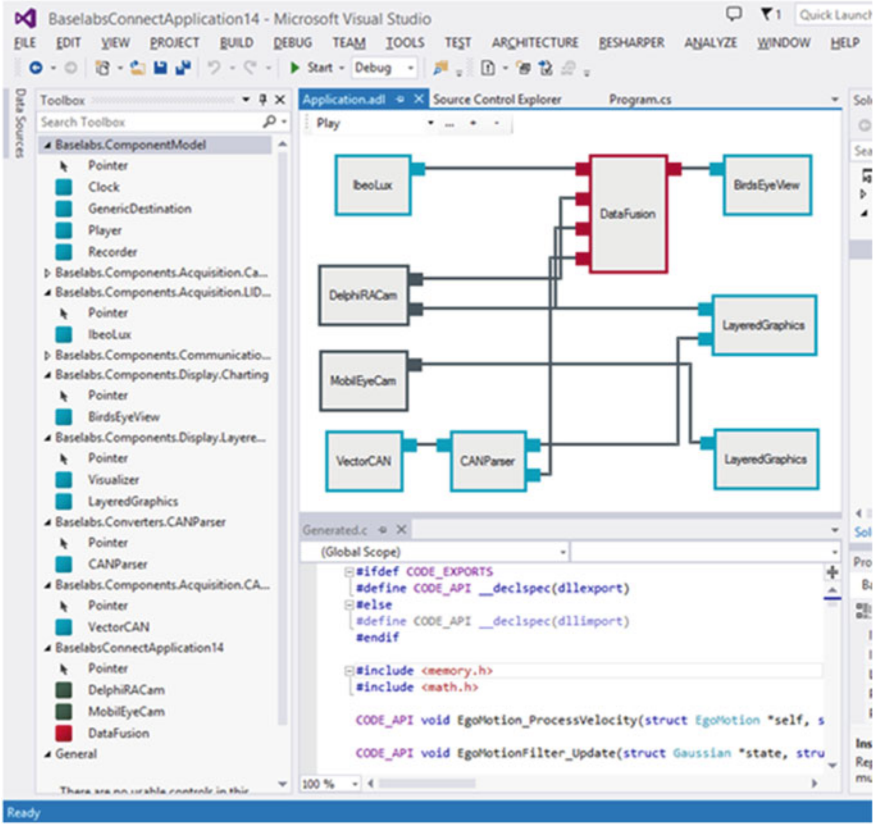
Fig. 1 Multiple object tracking

user interface offers a comfortable possibility to configure your own application in a very short time. CONNECT is shipped with a ready-to-use block-set, which enables the user to use typical ADAS sensors, transmit and receive data from different protocol implementations and logging data right from the start. The integrated sensor and component library, covers a wide range of typical use-cases for developing ADAS. Arbitrary sensors are supported out-of-the-box, and new sensors can be integrated with very low effort (Fig. 2).

Either use the ready-to-use block-set for integrating different kind of ADAS sensors (e.g. Camera Interfaces, IBEO Lux Laser-Scanner, GPS), or integrate your own specific sensor within the application.

The sensor data can be recorded in parallel on multiple hard discs, and the data is time-stamped and synchronized to ensure a reliable data basis.

This is done with the corresponding block-set. Network connection protocols (e.g., UDP, TCP, IPC), automotive bus protocols (e.g., CAN with integrated DBC-file support) and the communication protocols with ECUs (e.g., XCP with



```
#ifdef CODE_EXPORTS
#define CODE_API __declspec(dllexport)
#else
#define CODE_API __declspec(dllimport)
#endif

#include <memory.h>
#include <math.h>

CODE_API void EgoMotion_ProcessVelocity(struct EgoMotion *self, s

CODE_API void EgoMotionFilter_Update(struct Gaussian *state, stru
```

Fig. 2 Data processing for complex systems

A2L-file support) is integrated. Therefore, saving time is one main advantage of using CONNECT.

CONNECT provides in addition: IDE integration (e.g. Visual Studio), multiple data format support (e.g. MDF or ADTF *.dat), significantly less user code overhead, multiple programming language support, built in synchronization…

CONNECT offers an integrated C code generator, which is accessible with a single click. The generated C code is directly available (Fig. 3).

Furthermore the CREATE tool chain offer a sophisticated algorithm framework for sensor data fusion, probabilistic filtering and tracking.

Key features of CREATE:

- SDK and GUI for data fusion algorithm development
- Ready-to-use system and sensor models
- Suitable for arbitrary multiple sensor data fusion use cases

Algorithms developed with CREATE can be directly integrated into the CONNECT application (Fig. 4).

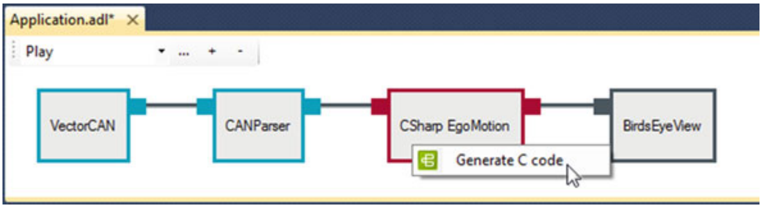


Fig. 3 C-Code generator

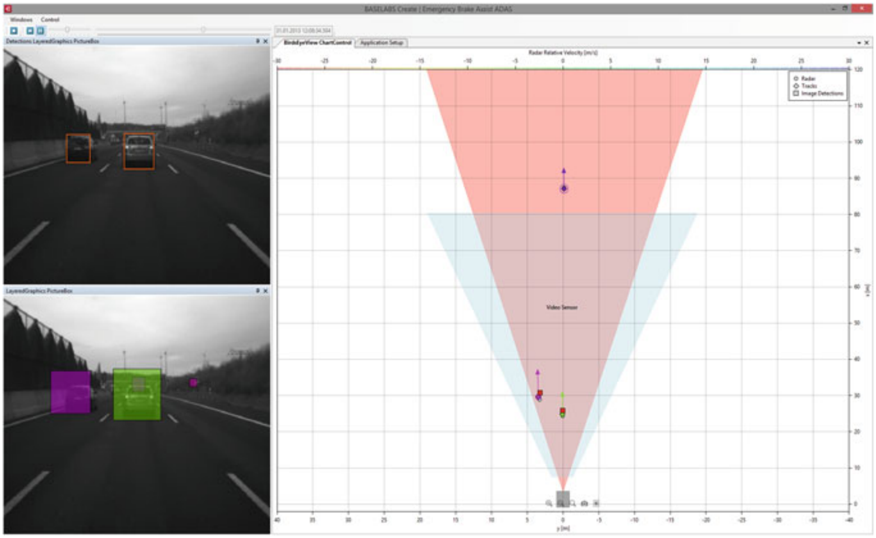


Fig. 4 Multi sensor scenario

In the development of ADAS, test and evaluation is an important step towards serial production. With its powerful data fusion, recording and replay capabilities, CONNECT is the right tool to handle the high data load in the evaluation of next generation systems. Multi hard disc recording and replay capability, the change of system settings during runtime and a reliable time stamping function make complex test procedures much more convenient.

4 High Speed ECU Measurement Hardware

For deeper analysis of ECU internal RAM values, nearly all ADAS ECU's requires a measurement bandwidth much higher than CCP or XCPonCAN.

The bandwidth requirement grows significant for all automotive areas in the last year, especially due to the increase of microcontroller core's and performance, which allows much more complicated applications resulting in more measurement signals and parameters (Fig. 5).

The highest bandwidth requirement has typically radar sensor with up to 30–40 MByte/s, especially when also the radar raw signals should be measured.

Depending on the microcontroller debug or data-trace interface following data-rates are possible (Fig. 6).

Using debug ports of microcontroller like JTAG, DAP, LFast, the ECU must copy the signals in the RAM for measurement, very similar like the standardized measurement concept via CCP, XCP.

The signal are measured task synchron, so there is a need for about 4 bytes per signal additional measurement RAM. This concept add ~3 % per 1 MByte/s additional CPU load (300 MHz CPU).

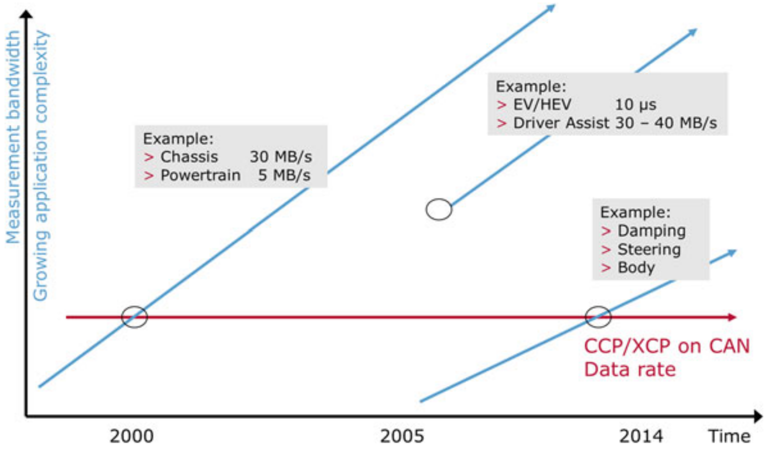
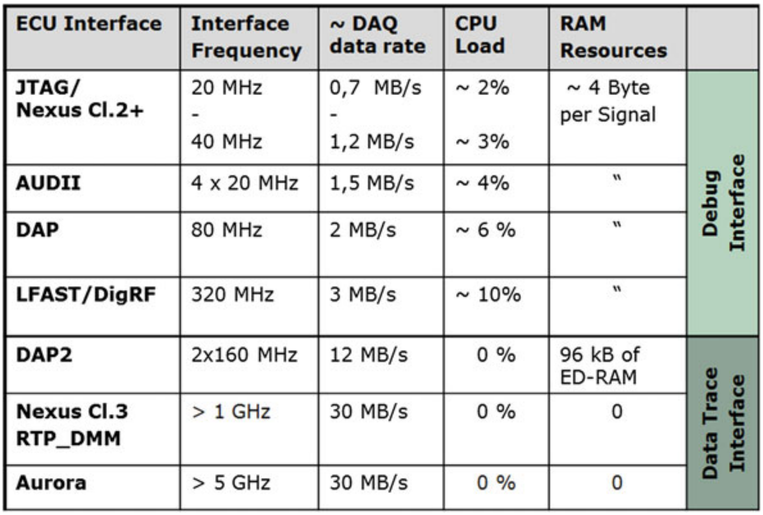
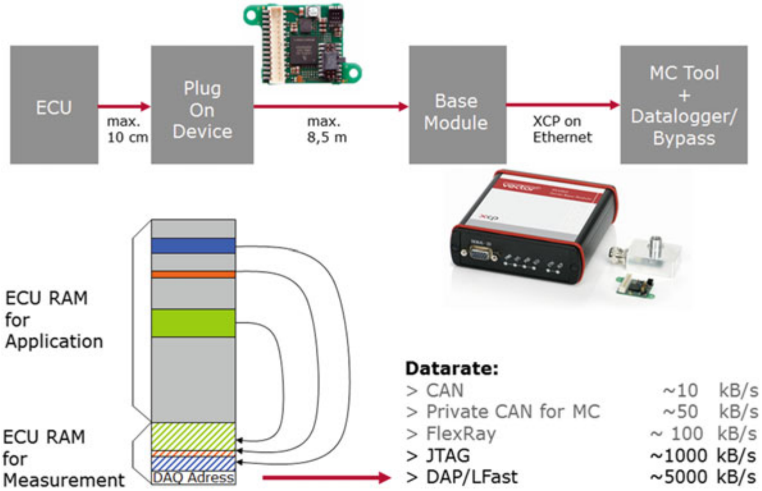


Fig. 5 Measurement bandwidth requirements



ECU Interface	Interface Frequency	~ DAQ data rate	CPU Load	RAM Resources	
JTAG/ Nexus Cl.2+	20 MHz - 40 MHz	0,7 MB/s - 1,2 MB/s	~ 2% ~ 3%	~ 4 Byte per Signal	**Debug Interface**
AUDII	4 x 20 MHz	1,5 MB/s	~ 4%	"	
DAP	80 MHz	2 MB/s	~ 6 %	"	
LFAST/DigRF	320 MHz	3 MB/s	~ 10%	"	
DAP2	2x160 MHz	12 MB/s	0 %	96 kB of ED-RAM	**Data Trace Interface**
Nexus Cl.3 RTP_DMM	> 1 GHz	30 MB/s	0 %	0	
Aurora	> 5 GHz	30 MB/s	0 %	0	

Fig. 6 Overview microcontroller interfaces



Datarate:

> CAN	~10 kB/s
> Private CAN for MC	~50 kB/s
> FlexRay	~ 100 kB/s
> JTAG	~1000 kB/s
> DAP/LFast	~5000 kB/s

Fig. 7 RAM copy measurement principle

Typical ADAS usecases: Autonomous parking, Lane Departure Warning ECU's, … (Fig. 7).

Dedicated high performance microcontroller from Infineon (Aurix) and Freescale/STM (MPC57xx) support the Aurora data-trace interface.

With this measurement principle any changes RAM are transmitted without any CPU load to the VX1000 system. VX1000 can reconstruct the RAM of the

Fig. 8 Aurora data-trace principle

microcontroller at any time, in consequence no CPU load and no additional RAM is necessary for the measurement up to 30 MByte/s.

Typical ADAS usecases: Radar ECU; Video ECU; Domain control ECU's for autonomous driving (Fig. 8).

Disadvantage of the Aurora principle is: Only a few microcontrollers support Aurora. The necessary POD (PlugOnDevice) in the microcontroller has the double size, water prove mounting is more complex and the POD is more expensive, than the POD for the RAM copy method.

A very good compromise offers the DAP2 interface from Infineon Aurix microcontroller, using a small POD, which is easy to water prove integrate into the ECU, less expensive and 12 MByte/s data-rate without CPU load possible (Fig. 9).

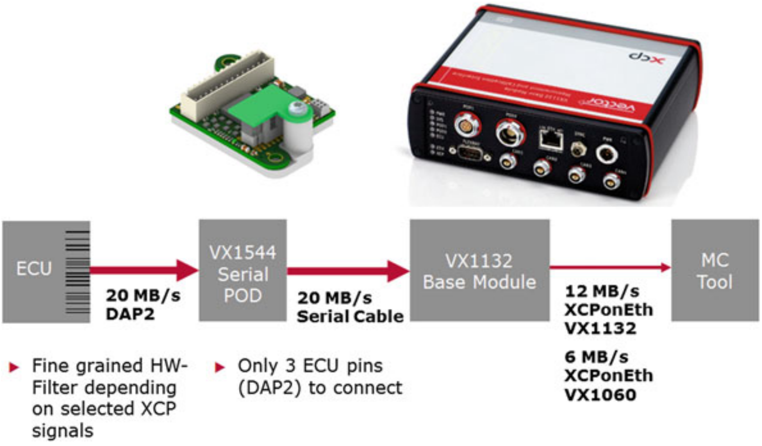


Fig. 9 Infineon DAP2 data-trace principle

5 Rapid Prototyping/Function Bypassing

Functional bypassing allows customer to execute parts of the ECU SW application outside the ECU on an external real time platform.

This offers the possibility to test a new algorithm without ECU reprogramming, further more it can be switch easily between ECU internal and external algorithm, to compare both algorithm.

The algorithm can be developed with Simulink or C, C++, C#.

As an example the bypassing solution for ADAS Domain Control Units (DCU's) for autonomous driving should be exanimated in more details.

Such DCU has typically 2 microcontrollers.

One µC is a typical automotive microcontroller like Infineon Aurix, Freescale/STM MPC57xx, Renesas RH850 supporting ISO26262 for functional safety requirements.

The 2nd µC is high performance microcontroller (with e.g. 4 × 1 GHz), and doesn't support the full automotive safety requirements.

Most of the OEM wants to develop the ADAS DCU application by them self, the Tier1 delivers in this case only the ECU hardware and basic software functions, like Autosar operating system, diagnostic, network management, …

In this case bypassing is very use full, because new algorithm can be easily and quickly tested in the lab or even on the road with all connected actuators and sensors, without ECU reprogramming.

The Vector Bypass solution consists 4 parts:

- VX1000 system for high performance ECU Read/Write access
- High-End Real-Time execution platform (Intel i7 with 2 × 2.7 GHz CPU)
- Simulink Plug-Into insert automatically Bypass functions into Simulink models
- Control and Display Tool for signal measurement of ECU functions and external function (Figs. 10 and 11).

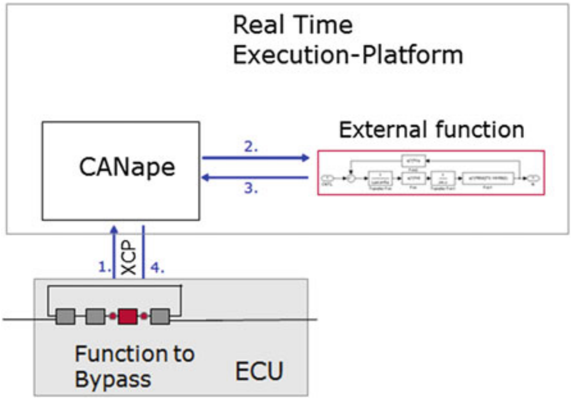
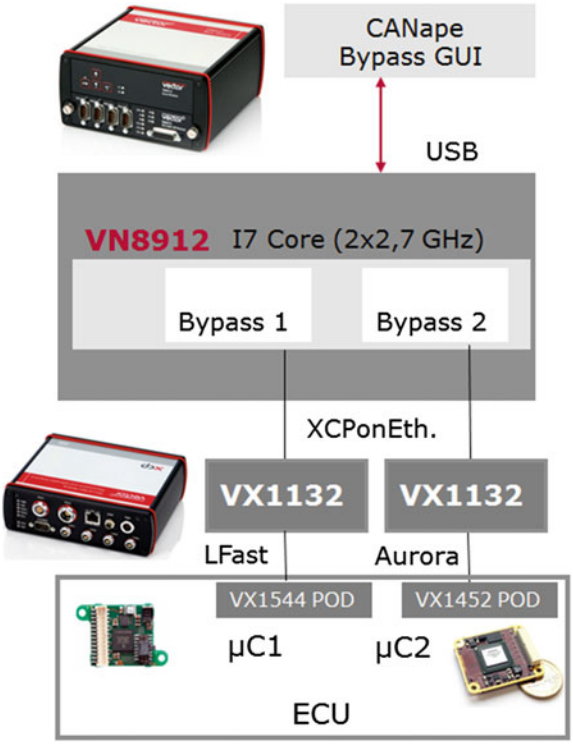


Fig. 10 Schematic of external function bypassing

Fig. 11 DCU Dual-μC Bypassing setup



For ADAS DCU bypassing with 2 micro-controllers, following setup can be used. VN8912 module is a powerful dual core bypass platform. Two bypasses can be parallel and independent executed. Two VX1000 systems for high speed ECU RAM Read/Write access will be connected via the standardized XCPonEthernet protocol with the VN8912.

To the ECU software a switch must be inserted to either execute the ECU internal code (red square in Fig. 10) or the external code (blue bypass path in Fig. 10).

In case of C-Code the bypass software switch must be inserted manual in the code. The VN8912 requires for the external bypass an executable C-dll.

If simulink is used for algorithm development, Vector offers an automatic bypass generation for Simulink subsystem.

First the Vector Simulink Plug-In must be installed, then the subsystem to bypass can selected, and the VCreateBypass function can be executed (Fig. 12).

A Bypass enable block will be inserted, which allows to switch the bypass on (e.g. during development process) or off (e.g. for the ECU serial release) If the

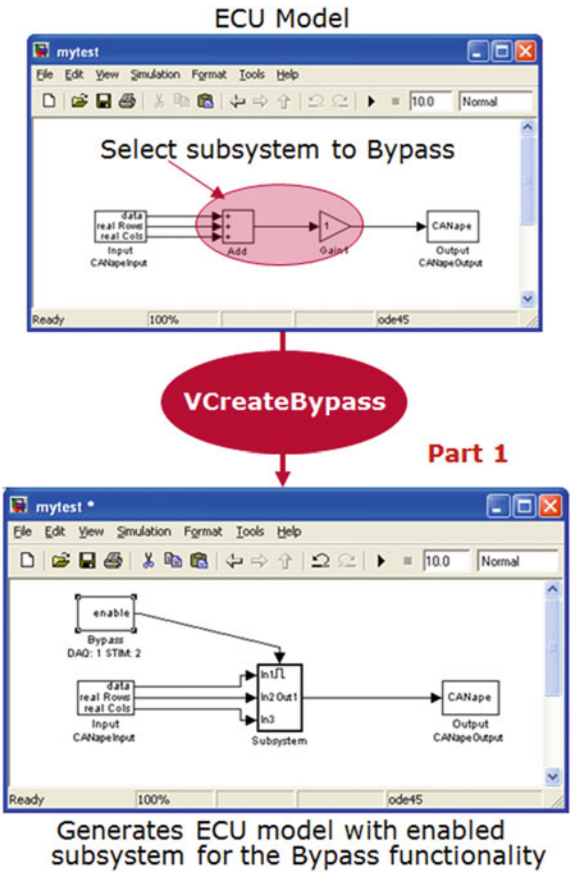


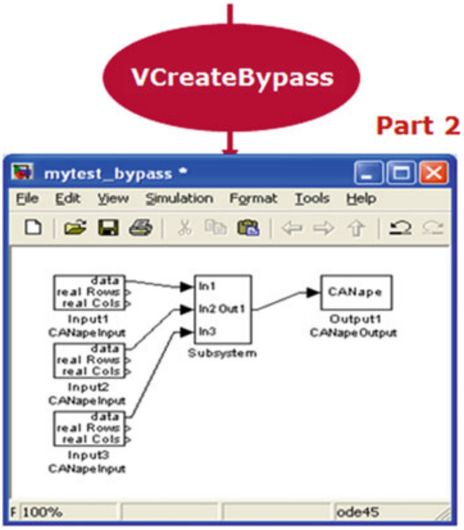
Fig. 12 Automatic bypass generation

bypass is enabled during code generation of the simulink code, the bypass hock with bypass supervision timeout will automatically inserted in the generated simulink code.

In the CANape display tool, it is then possible to decide, either to execute the internal function, and use the external bypass only to compare the signal values which are calculated with the external bypass, or to substitute the internal function with the external bypass.

Second the subsystem will be cut out and Vector Simulink IO-Blocks can be connected with the Simulink IN and OUT blocks. Finally a *.dll for the VN8912 can be easily created (Fig. 13).

The VN8912 high performance bypass execution platform, supports parallel bypass execution. Either the CANape tool can be connected for visualization or VN8912 can be also used in standalone mode.



Subsystem for execution on the Real-Time platform with comfortable IO-blocks

Fig. 13 Bypass dll for external execution

6 ADAS ECU Road Validation and Data Logging

OEM's has usually the need for a supplier independent validation for various kinds of ADAS system and use cases, while Tier1 has more detailed requirements on such a tool.

Requirements to an ADAS validation tool like CANape

- Display of detected objects from Sensor/ADAS ECU into different views like: Video-view, bird view, map's
- Automatic transformation of object information from world coordinates into picture coordinates
- Easy calibration of the test camera (for the transformation calculation)
- Comfortable configuration of the object display
- Display of most probable path received via CAN from an ADASIS horizon provider
- Time synchronized with other ECU information:
  - CAN, FlexRay, Broadr-Reach bus-logging
  - XCP Signals (e.g. via VX1000 system)
  - External IO measurement devices
  - Diagnostic data
  - Simulink/State-Flow View

Fig. 14 ACC ECU bird and video display

Fig. 15 LDW ECU bird and video display

Object configuration:

Many predefined object such: line, square, triangle, cubes, polygon curves, circles, park objects, traffic sign are available in an easy to configure object editor (Figs. 14 and 15).

For easy lane departure warning testing, the length and type of the lanes detected from ECU are drawn into bird and video view. CANape also check, if lane signals are valid or no (Fig. 16).

Fig. 16 Display of ADASIS stubs in GPS window

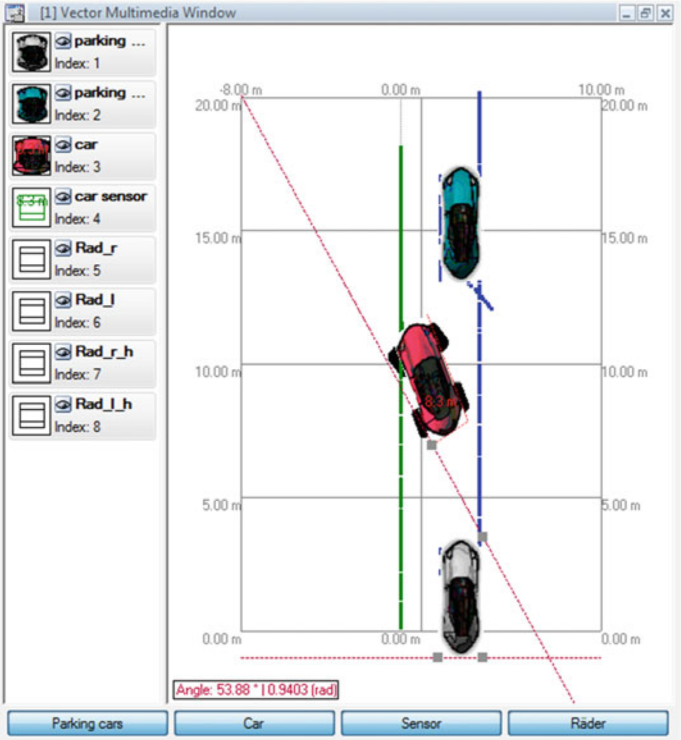


Fig. 17 Test setup for autonomous parking

CANape can draw all probable paths in different colors received from the ADASIS horizon provider into the map, time synchronized with all other measurement signals (Fig. 17).

Complex autonomous parking situation can comfortable setup, and tested.

7 Conclusion

Vector offers a solution covering the whole development process of any ADAS use case.

A challenge for the future will be to find a solution to log ECU and raw data with up to 500 MB/s for complex autonomous driving use case.

Methodology to Assess and to Validate the Dependability of an Advanced Driver Assistance System (ADAS) Such as Automatic Emergency Braking System (AEBS)

S. Geronimi, V. Abadie and N. Becker

Abstract Amongst automotive functionalities which generate brakings like AEBS, it is necessary to assess the consequences of an inopportune braking in the presence of a following vehicle. In order to meet this requirement, a specific methodology was developed. This methodology uses data recorded on open roads and the ISO 26262 fundamentals. The main risk for ADAS function in particular for automatic braking, is to trigger a braking which can be perceived as inopportune, whereas the vehicle is followed by another vehicle which does not react quickly enough and collides. In order to define the failure rate criterion, we use the relation between the "pre-existing risk" and the product Exposure (E) by Controllability (C) for each Severity (S). By using data from accidentology, it is make it possible to evaluate the pre-existing risk and using a recorded database, compute the product [E × C]. Finally, the methodology allows to define the failure rate requirement necessary to drive without safety-related incident in order to validate the function.

Keywords Safety · ISO 26262 · AEBS

1 Introduction

This paper describes a methodology to evaluate a given aspect of dependability allocated to a safety system on a vehicle, such as the Automatic Emergency Braking System: the treatment of erroneous braking in a follow-up scenario.

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J. Langheim (ed.), *Energy Consumption and Autonomous Driving*,
Lecture Notes in Mobility, DOI 10.1007/978-3-319-19818-7_13

To study this type of Automatic Braking function, PSA takes the ISO 26262 standard as a starting point in inopportune and erroneous braking situations, even if it is not explicitly the main focus of this standard.

When we consider inopportune braking, we mean this is triggering a braking whereas all the components (sensors, actuators …) did not fail. The other failures instances (mechanic, hardware, software…) are covered by standard tools and methods of dependability.

2 General Principles for the ISO 26262 Standard

2.1 ASIL Ranking/“Pre-existing Risk”

ISO 26262 [1] is the adaptation of IEC 61508 [2] to comply with needs specific to the application sector of electrical and/or electronic systems within road vehicles. ISO 26262 addresses possible hazards caused by malfunctioning behavior.

Hazard analysis and risk assessment lead to the ASIL (Automotive Safety Integrity Level) definition with:

- Exposure (E): state of being in an operational situation that can be hazardous if coincident with the failure mode under analysis
- Controllability (C): ability to avoid a specified harm or damage through the timely reactions of the persons involved, possibly with support from external measures,
- Severity (S): estimate of the extent of harm to one or more individuals that can occur in a potentially hazardous situation.

A way to define the risk when studying an AEBS function is:

$$R = E \times C \times E \times FR$$

being R the pre-existing risk for the function and FR, the failure rate criterion of inopportune braking.

To validate the AEBS function, we need to define the value for the failure rate criterion for each severity values defined in the standard (Cf. Table 1 in [3]).

$$FR(S_k) \leq Risk(S_k)/[E \times C](S_k)$$

being K = 1, 2 and 3.

Finally to assess the failure rate criterion, we have to evaluate the “pre-existing risk” and the product [E × C], exposure by controllability.

3 Application to the AEBS Function

3.1 Product [E × C](Sk)

The assessment is carried out using a driving database ("follow-up database"), in which follow-up situations have been recorded on open roads, (naturalistic driving, with systematic recording a vehicle presence, the distance and the relative speed from a preceding vehicle). This database has been built with various drivers, driving every day with the vehicle as if they were theirs. The content of the database has to be compliant with the usage of the targeted vehicle which is going to carry the AEBS function.

Special attention must be paid to building up the database in order to be representative as accurate as possible the "average" behaviour of driver but also to set up a collection of situations, scenarios, roads comparable with those which could be met by the vehicle carrying the AEBS function.

This database contains samples statistically representative for the market targeted, based on the relative positions of vehicle being followed similarly.

On this driving database, an automatic braking occurring with each step of time is simulated with the profile of deceleration under scrutiny for the studied function (this deceleration is measured by the amplitude according to time and the duration of braking).

The driver's behavior of the following vehicle is assessed by defining two parameters:

- His reaction time: he reacts in "x" second after the triggering of the automatic braking of the vehicle with the AEBS function,
- The way he is braking: he brakes according to a deceleration profile until "y" m/s^2.

The simulation aims to determine if the two vehicles would collide by defining the level of severity.

Obviously, the driver's behavior of the following vehicle has to be adapted to the deceleration profile of the AEBS function. The reaction will not be the same if the inopportune braking leads to an immediate stop with a strong deceleration or a braking comparable to a function of cruise control (like a Adaptive Cruise Control) deceleration around 4 or 5 m/s^2.

Indeed, the driver analyzes how he needs to decelerate according to the way he perceives the deceleration of the vehicle in front and the distance which separates from this vehicle.

The two parameters described above, characterizing the following vehicle must be defined by using data from the literature, the accidentology and from experiments carried out on tracks or with a driving simulator.

For each time step of the database, an automatic braking is computed and the results as speeds of each vehicles or relative speed at impact can be determined. These values allow to assess the severity of this hazardous braking.

When simulations are carried out, the times spent by the vehicle in the situations of S1, S2 and S3 potential severity is obtained and compared to the total time of the database in order to obtain a rate.

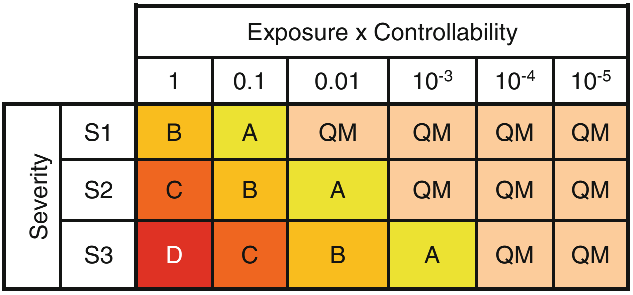
The product [E × C](Sk) with k = 1, 2 and 3 is thus calculated.

At this point, the share of the time spent by the vehicle in situations leading to S1, S2 and S3 impact severities is established.

Therefore, the exposure is worked out through the time spent in each severity and the controllability is evaluated through the behind driver's reaction.

This calculation, could also give an "equivalent" ASIL ranking while referring to the ISO 26262 standard table.

Table A



		Exposure x Controllability					
		1	0.1	0.01	10^{-3}	10^{-4}	10^{-5}
Severity	S1	B	A	QM	QM	QM	QM
	S2	C	B	A	QM	QM	QM
	S3	D	C	B	A	QM	QM

3.2 *"Pre-existing Risk" Assessment*

To determine the failure rate criterion of erroneous braking, we have to evaluate the pre-existing risk of this hazard.

Different methods can be used to answer this question. There are at least, three methods used in the industry and in different countries.

- "Minimum Endogenous Mortality" (MEM). The principle is that hazards due to a new system must not significantly augment the Endogenous Mortality Rate (EMR) of a young person. The EMR is the rate of death due to illness, disease or congenital malformation. In practice, the level of risk is interpreted as 5 % of the EMR, or a 1 in one hundred thousand chance of death per person per year [4].
- "As Low As Reasonably Practicable" (ALARP). The principle is based on the fact that "reasonable" and/or "practicable" actions must be developed to reduce the risk until obtaining a "negligible" risk.
- "Globalement Au Moins Aussi Bon" (GAMAB) and "Globalement Au Moins Equivalent" (GAME) meaning "globally at least as good". The principle requires that any new system be at least as good as the system it is replacing, or any equivalent system in existence. This principle ensures that a new system does not go backwards in terms of safety.

These three methods do not allow us to assess fully a “pre-existing risk” in introducing an ADAS on a vehicle.

Using the GAME method based on the premises that a function must be as good as an “average” driver and at the same time using the MEM method based on the premises that the mortality rate must not be increased by 5 %, we can define the “pre-existing risk”.

This way, the “pre-existing risk” assessment is based on the accident risk which one faces on the roads nowadays and using it like an objective in order to make sure that a new function should not significantly increase the accident rate.

Therefore, data from accidentology have been used. It is possible to define various rates: dividing the number of total accident by the travelled roads or the number of deaths diving by the population and the time spent on roads.

The data used come from the available databases from Europe or from the geographical location targeted for the function.

Each rate is linked to a severity level: the death rate will be related to S3, the whole accident rate to S0.

This approach could finally define the risk observed on roads. The “pre-existing risk” for the AEBS function could be defined by introducing a 1/20 factor on the value compliant with accident data according to the MEM principle. Similarly, a factor 10 between the “pre-existing risk” for S1, S2 and S3 is introduced to respect to respect the scale factors found in ISO 26262 standard.

Therefore, a “pre-existing risk” for each severity has been defined.

Note: the use of the latest available statistics makes it possible to bring up to date the targets of “pre-existing risks” and thus to take into account the accidents rate evolution.

3.3 “Failure Rate Criterion”

Once the “pre-existing risk” for each class of severity defined, the expression [5] is used to determine the target for the “failure rate criterion”, it represents for each severity.

The final value is the lowest value of the three “failure rate criterions”, and the target occurrence for the erroneous braking of the AEB function.

An illustration of this calculation is shown below.

Simulation based on the database		
[E × C](S1) Time spent in S1	[E × C](S2) Time spent in S2	[E × C](S3) Time spent in S3
1.71 %	0.27 %	0.01 %
1.72×10^{-2}	2.7×10^{-3}	1×10^{-4}

Using Table A, an equivalent ASIL ranking is obtained:

S1	S2	S3
1.72×10^{-2}	2.7×10^{-3}	1×10^{-4}
[0, 10, 01]	$[0, 01 \times 10^{-3}]$	$[10^{-4} \times 10^{-5}]$
ASIL A	ASIL A	ASIL QM

By introducing the "pre-existing risks" (for example) for each severity level, it is possible to calculate the "failure rate criterions".

	S1	S2	S3
[E × C]	1.72×10^{-2}	2.7×10^{-3}	10^{-4}
"pre-existing risks"	10^{-6}	10^{-7}	10^{-8}
"failure rate criterions" (1/h)	5.8×10^{-5} $(=10^{-6}/1.72 \times 10^{-2})$	3.7×10^{-5} $(10^{-7}/2.7 \times 10^{-3})$	10^{-4} $(10^{-8}/10^{-4})$
Min value = failure rate criterion (1/h)	3.7×10^{-5}		

4 Validation of the Requirement

Once the failure rate of inopportune braking obtained, it is necessary to prove that the function meets this objective.

4.1 *Objective for a Driving Validation*

To validate the objective, it is necessary to assess the number of hours and/or the number of kilometres of driving.

A way to evaluate these numbers is to use the logics introduced in the standard for the definition of minimum service period without safety-related incident (Cf. Note 3, 4, Table 9): the confidence level value employed is 70 %.

For "X" in (1/h) failure rate, if driving of 1.2 dividing by "X" hours is done without erroneous triggering, one can consider with a confidence level of 70 % that the function is compliant with the objective.

As per our example:

	Confidence level (70 %)
Failure rate criterion (1/h)	3.7×10^{-5}
Minimum service period without safety-related incident (h)	32,400 (=$1.2/3.7 \times 10^{-5}$)
Minimum kilometers without safety-related incident (km)	1,296,000

The transition from the number of hours to the number of kilometres is obtained by making the assumption that on average, 40 kilometres per hour are driven out by a vehicle.

To sum up in our example, by driving at least 1.3 millions of kilometers, one must ensure that the AEB function will be compliant with the objective previously defined.

Obviously, these kilometers have to be drive in the same conditions as the database used for the simulation. It means that the driving must contains various types of roads, various weather conditions, various traffic conditions….

5 Conclusion

This paper has provided a method to assess and to validate the Automatic Emergency Braking System (AEBS) by taking into account an erroneous braking when the vehicle is followed by another.

On the basis of the ISO 26262 standard and by using data from accidentology as well as safety methods, this paper proposes a way to define an objective of driving to ensure to have a vehicle equipped with a safe AEB function on roads.

Acknowledgments The authors acknowledge the contribution of their colleagues to this work.

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Methodology for ADAS Validation: Potential Contribution of Other Scientific Fields Which Have Already Answered the Same Questions

G. Yahiaoui and P. Da Silva Dias

Abstract Since the 80s, the building of learn and test data bases for learning-based systems (i.e. neural networks) had to cope with problems of picking representative examples and measuring the generalization/the score of the system. And of course, real open world applications cannot be fully tested. It seems that artificial vision-based ADAS now discover the same question, and then, may use the same solutions, involving the same methodology (A.G.E.N.D.A.), using design of experiments and data analysis tools.

Keywords Factors of variability · Testing · Open world systems · Methodology AGENDA · Design of experiments · Data analysis · Efficiency · Testing · Validation

Glossary

ADAS	Advanced Driver Assistance Systems
s/n ratio	signal/noise ratio

1 Introduction

Advanced Driver Assistance Systems implement general sensors, such as cameras, for instance, creating multidimensional signals. Each dimension, or measurement channel into an image, is called a pixel. Each pixel is a light sensor (brightness and color). This sensor is sensitive to all light emission in a given range of wavelengths. By comparing the output of thousands of sensors (forming the image) one can transform this multidimensional light sensor in an ADAS sensor (for example: a "pedestrian detector"). Then it is a computer program that is responsible for extracting the information sought by comparison of measurement channels (pixels), which allows decide 'absence' or 'presence' of a pedestrian.

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This computer program applies algorithms and heuristics that are tested in a number of cases that are supposed to be important in order to validate their effectiveness. The Automotive Industry use to apply the so called “One Million Kilometers” validation test.

The problem of the formal validation of these algorithms and heuristics (“image processing”, “pattern recognition” methods) is that it is difficult to predict their performance in all possible cases. Indeed, if you consider an image of 1 million 8 bits pixels, then there are 2,561,000,000 possible images. This huge number of possible messages (as defined in the information theory [1]) is the cardinal of the population of images. A complete validation should test the processing system for every possible message. So one can notice that the “one million km” validation procedure doesn’t make sense regarding this huge number of possible messages.

Engineers use to test the system on cases deemed interesting. This leads then to create a validation/test database of several hundreds or several thousands or even maybe several millions images. Whatever, this number of cases used for test and validation is very small compared to the number of possible messages. So you see that the validation of a system using cameras in an open world (such as ADAS) is then a complex issue.

This paper presents other sectors or other types of applications for which the validation poses the same kind of problems, and where solutions have been developed.

We describe those solutions and see how to build from there a draft methodological validation for ADAS.

2 Learn and Test Data Bases for Learning-Based Systems

Learning-Based Systems need only ONE thing to be tuned perfectly: “the” examples. But in general you only have “some” examples plus knowledge (about how these example could change for different situations). The question was “how to use this knowledge” in order to build a good learn data base (the data base that allows the system to learn properly) and to build the good test base (the data base that allows to validate the system).

It has been shown that it is possible to use design of experiment on factors of experiments [2] using the methodology AGENDA [3].

The methodology builds every possible crossing of every factors of variability.

Then rare facts are as well represented than usual facts: this is not true if you take your example in a complete random way. But keep in mind that road safety must take into account rare facts as they may be the cause of accidents.

So, for neural networks validation as for ADAS validation, taking “many” examples in a random way is not a good idea at all.

3 Application to ADAS Validation

3.1 List of Factors of Variability

Building a validation data base for a vision based ADAS should then consist in:

- listing the factors of variability (the knowledge that you have on the problem).
- building a complete design of experiments to sample this variability factors space.
- building factional orthogonal designs of experiments [4] to decrease the number of examples to keep into the validation data base.

Let us do this work for a camera-based "road detection" system (as an example): Factors of variability may be structured in several kinds:

- sensor variability
  - Internal parameters of the camera
  - External parameters of the camera settings
  - Spatial resolution
  - s/n ratio
  - black threshold level
  - gain
  - white level light
  - number of bits

NB: you may consider that these parameters may be constant values… but beware, in industrial projects, there are releases among time (with possible new generation camera), and industrial processes are not always precise (example: precise location of the camera into the car).

- global scene variability
  - kind of light (cloudy day, sunny day, sunny dawn/evening/sunrise, night in the city, night in countryside,…)
  - kind of scene (urban, road, highway,…)
  - weather (dry, rain, fog, snow,…)
  - traffic (no one, average, heavy)
  - road signs (no white lines, exhausted white line, regular white lines,…)
  - road shape (curve, straight,…)
  - color of the road (grey/blue, red,…)
  - texture of the road (exhausted, new,…)

- special characteristics
  - presence of obstacles (pedestrian, construction work,…)
  - etc.…

Then one can see that even if only consider 10 factors that may take 3 positions, then you should build a data base with 3^{10} examples.

Of course, it is possible to take less examples using factional designs of experiments.

3.2 How to Take Those Examples

In many applications, the combination of some factors of variability may not be encountered while driving, even millions and millions of kilometres.

The solution may be:

- filter big data bases (using human beings, or off-line automatic detection systems)
- change the context during measurement (send water on the car, on a sunny afternoon, in a curve, etc.…)
- use computer simulation

The key is that you must know the combinations that you never tested.

Whatever the method, it is a very tough job, and this should be done in a systematic way.

NB: The score of your adas must use statistical estimators (and not invented ratios that are usually biased):

- Khi-2 if your output is a classification [5]
- correlation if your output is a quantitative variable (a score) [6]

You may also add "automatics" quality estimators such as "distances" (and there are many candidates).

All the efficiency scores are computed on the same validation data base (for every application).

You may ponderate the crossings of variability factors if you consider that your system must be qualified for a number of kilometers without failure or for a given time without failure.

4 Data Analysis and Online Confidence Estimation

Because the validation is an orthogonal sample of every known factors of variability, it makes sense to analyse the data base of inputs of your ADAS:

- statistics: average values and standard deviations
- factorial analysis: eigen vectors of the data base and eigen values [7].

These computed elements let you build a multidimensional "shape" of the input data base. If you are able to compare the onboard inputs to this recorded shape, then you know:

- if the current image corresponds to already seen cases
- if the current image is completely new.

And of course, you can compute a score.

Than it is possible to give a confidence measurement of the system in the open real world, depending on the closeness to validation data base shape.

And because the design of experiments is orthogonal, rare events are as well represented by the shape that ordinary events.

5 Conclusion

This paper has provided some ideas that consist in using methodology and statistical tools developed for neural networks, because the problems of validation are quite similar.

The use of such a methodology should be implemented in a system that would allow:

- real time recorded images and signals replay system
- simulation system: computer simulation, and also "car in the loop" simulation systems

We think that car manufacturers should gather with data analysis and validation teams, in order to mutualise this tough work that may lead to official validation for ADAS and maybe for autonomous vehicles too.

Such a work is possible but may take 2 or 3 years to build the proper design of experiment and to chose the proper statistical estimators for efficiency measurement.

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Part VI
CO_2 Reduction, Hybridization, Regulation

A Green Light Optimal Speed Advisor for Reduced CO_2 Emissions

B. Bradaï, A. Garnault, V. Picron and P. Gougeon

Abstract Automotive industry is facing challenges to reduce CO_2 emissions. A promising approach consists in anticipating the road profile and the upcoming dynamic events like traffic lights. V2X technologies enable this anticipation and allow CO_2 emission reduction as well as traffic flow improvement. This topic has been addressed in the framework of the French public funded project Co-Drive, with the use of traffic lights data broadcasted to vehicles. One of the developed functions by Valeo within the Co-Drive project is a Green Light Optimal Speed Advisory (GLOSA) system. This system coaches the driver to adapt his vehicle speed in order to safely pass the next traffic lights during the green phase. It allows reducing stop times and unnecessary accelerations in urban traffic situations and therefore saving fuel and reducing CO_2 emissions. Indeed, state-of-the-art studies showed the great potential of GLOSA systems in terms of CO_2 emission reduction and traffic flow improvement with different approaches. Here we present a description of the GLOSA system that has been implemented on a Valeo demonstration car. It has been tested with promising results and got very positive feedbacks from customers and public authorities. Next developments of V2X communication like green phase for emergency vehicle approaching, traffic light violation signal, or adaptive routing will allow further improvements in CO_2 emission reduction, safety and comfort.

Keywords GLOSA · V2X · Eco-coaching

Glossary

ADAS	Advanced Driving Assistance System
V2X	Vehicle to Vehicle or Vehicle to Infrastructure
HMI	Human Machine Interface

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GLOSA	Green Light Optimal Speed Advisor
ITS	Intelligent Transportation System

1 Introduction

Road transport contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2), the main greenhouse gas. Indeed, CO_2 emissions from road transport increased by nearly 23 % between 1990 and 2010. Light-duty vehicles—cars and vans—are a major source of greenhouse gas emissions, producing around 15 % of the EU's emissions of CO_2 [1].

Car manufacturers and their providers are working on Intelligent Transportation Systems in order to reduce CO_2 emissions and fuel consuming.

A promising approach consists in predicting the upcoming road profile, to anticipate energy recovery events (traffic lights, stop signals, roundabout, slope…) in order to manage the battery state of charge, and identify electric driving areas (low speed limit, congested driving, parking…) [2].

To go further in that way, this approach can also be used to assist eco driving. For instance, by activating automated vehicle functions, such as "connected" injection cut off time control before deceleration, energy recovery can be maximized [3].

Another approach uses V2X technologies that enable traffic lights data emission and allow CO_2 emission reduction as well as traffic flow improvement by coaching the driver. This topic has been addressed in the framework of the French public funded project Co-Drive, with the use of traffic lights data broadcasted to vehicles.

This paper presents the implementation and the results of GLOSA solution.

In the Sect. 2, the context of this study is presented. Then, the GLOSA function and finally the experimental results are presented.

2 Context

2.1 Co-Drive Public Project

The French funded public project Co-Drive aimed to validate a pre-industrialization approach towards a cooperative driving system between User, Vehicle and Infrastructure in order to suggest an intelligent, secure and calm route, for sustainable mobility [4].

The project duration was 3 years, and ended on February 2014.

The results of the project include prototype systems that detect incidents on the road and measure traffic data with the embedded devices, as a mobile traffic sensor. These prototypes allowed sending information to traffic information service system and highway management system. With the data received, these systems were able

Fig. 1 Co-drive system

to disseminate information about traffic or incidents to the on-coming vehicles before they reach it.

The data transmission from vehicle to infrastructure used both VANET and cellular network.

The second system developed in the framework of the Co-Drive project making the link between the vehicle and infrastructure is a cooperative traffic light. It enables a safe crossing of the intersection with reduced CO_2 emission thanks to a *Green Light Optimal Speed Advisory* system (GLOSA) (Fig. 1).

2.2 V2X Communication

Vehicular communication, also called V2X for Vehicle-to-Vehicle or Vehicle-to-Infrastructure communication is a growing topic of interest in the scope of Advance Driving Assistance Systems (ADAS) and Automated Vehicles. It increases the field of view of the vehicles about their environment, enabling them to know a situation in advance, for example traffic jam, black ice, or other vehicles presence and intentions.

Vehicular communication also enables cooperation between agents, such as platooning for cruising vehicles, or green light requests for emergency vehicles approaching traffic lights.

The targeted goal with the use of V2X in combination with ADAS is to increase safety and traffic efficiency.

3 GLOSA

3.1 Principle and Objectives

The objective of GLOSA systems is to provide to the driver the optimal speed in order to cross the next intersection during a green light phase.

It uses data sent by the infrastructure through vehicular communication (12 V—Infrastructure to Vehicle) to describe the intersection topology and the traffic light cycles that apply to the intersection, and information about the car approaching the intersection to calculate the optimal approaching speed.

3.2 Expected Benefits

GLOSA systems improve traffic efficiency by:

- reducing stop times for traffic fluidity
- giving more information about handling intersection for road safety
- avoiding unnecessary acceleration to reduce CO_2 emission

This kind of system can also be used to reach a Green Wave, where several traffic lights are coordinated by the infrastructure to ensure continuous flow of vehicles.

3.3 A GLOSA System Implementation

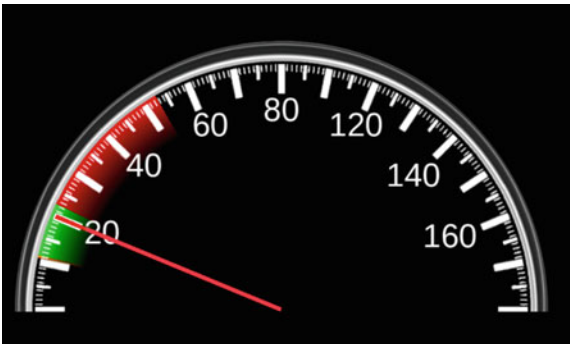
A first implementation of a GLOSA algorithm was done based on the algorithm presented by Katsaros et al. [5]. During test drives, users gave good feedback about the feature, but it appeared that giving the driver textual information for GLOSA was not an intuitive way for advising about speed.

A second implementation based on this algorithm targeted a better Human Machine Interface through quick reading and comprehension of the information with intuitive driving function, giving the driver the speed ranges corresponding to the phases of the next traffic light. This HMI is shown in the Fig. 2.

4 Experimental Results

The goal of the experiments is to quantify the gains of a GLOSA system for crossing an intersection with a traffic light, measured on real conditions.

Fig. 2 GLOSA HMI



4.1 Equipment

The equipment consists of:

Traffic Light: controllable traffic light equipped with communication devices to transmit infrastructure data to the approaching vehicles, such as:

- ID of the traffic light
- Timestamp
- Latitude
- Longitude
- Current phase
- Remaining time of the current phase
- Green phase duration
- Amber phase duration
- Red phase duration

The traffic light control is embedded in a Raspberry Pi computer, which provides features to switch on and off lights of the traffic light commuting relays, and networking facilities to send the above data to the V2X equipment through Ethernet connection. The V2X equipment is composed of a IEEE 802.11p compliant WiFi router [6] and an antenna mounted on the traffic light, to transfer the data to the approaching vehicles (Fig. 3).

Vehicle: The vehicle used is a Peugeot 207 on which mileage, speed and CO_2 emission can be measured for the experiment. The vehicle is also equipped with a V2X communication device to receive data from traffic lights and provide it to the calculation unit. This car is presented in [3].

Smartphone: a Smartphone is used as:

- The sensing unit that receives data from the traffic light via the V2X device embedded in the vehicle, and can retrieve localisation and speed data with the embedded GPS system.

Fig. 3 Traffic light equipment scheme

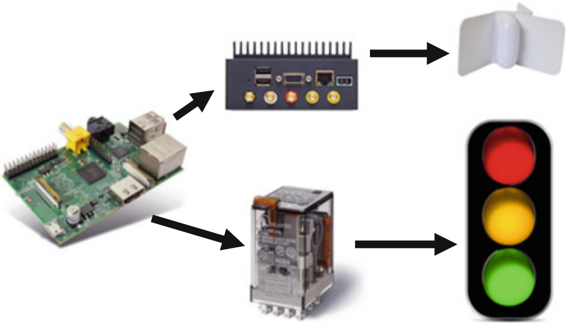


Fig. 4 Prototype for cooperative traffic light

- The calculation unit that processes the perception data
- The Human Machine Interface to deliver the Green Light Optimal Speed to the driver (Fig. 4).

4.2 Parameters

The experiment took place on a speed ring test track, with 2 set-up traffic lights as shown in the Fig. 5.

The two traffic lights had the same cycle:

- Red: 30 s
- Amber: 3 s
- Green: 25 s

The two traffic lights were not synchronised.

They were 1500 m far from each other.

No other vehicle was involved in the test.

4.3 Qualitative Results

The measures presented show the effects of a GLOSA system for crossing an intersection with traffic light in terms of speed and CO_2 emission.

Figure 6 shows the speed profile with and without GLOSA system for the same situation of approaching a traffic light.

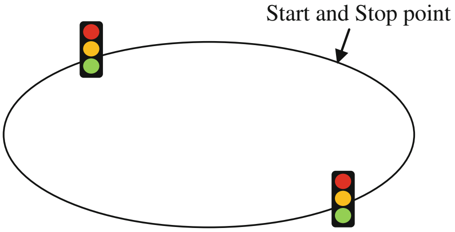
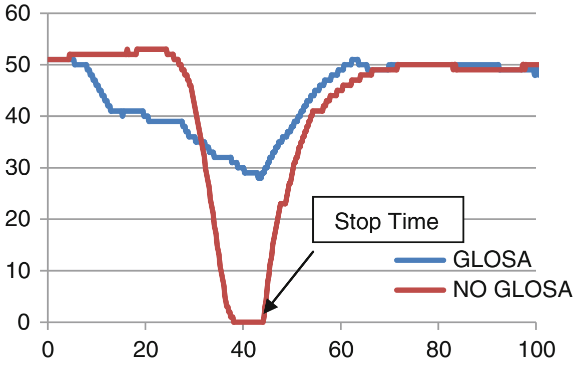


Fig. 5 Traffic lights set-up on test track

Fig. 6 Speed (km/h) versus time (s)



It shows that there is no stop time at the traffic light with the GLOSA system, and the speed variations are smoothed.

Figure 7 shows the gain in time for crossing an intersection by slowly decreasing the cruising speed as advised by the GLOSA system.

Figure 8 shows the difference in CO_2 emission for the same situation.

The CO_2 emission reduction is due to the facts that there is no stop time when using the GLOSA system, and that the acceleration phase after the traffic light is reduced.

4.4 Quantitative Results

The situation described above has been repeated to verify the reduction in CO_2 emission, measured with the GLOSA system activated.

Fig. 7 Distance travelled (m) versus time (s)

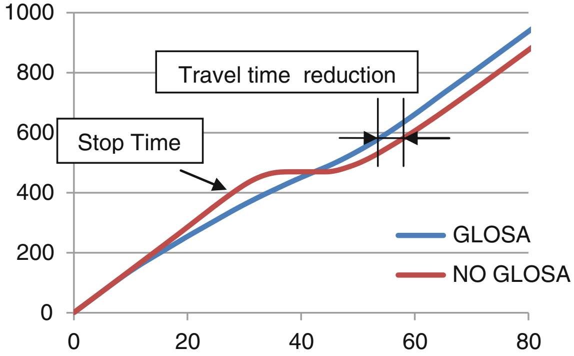


Fig. 8 Cumulated CO_2 emission (g) versus distance travelled (m)

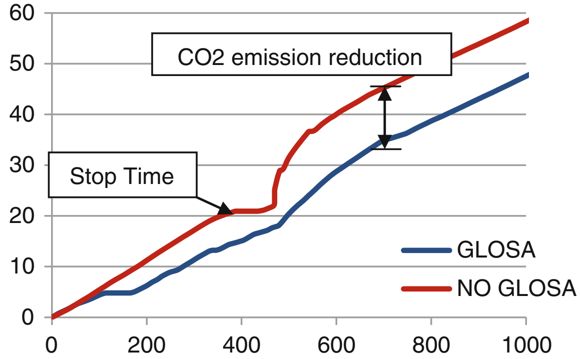


Fig. 9 Cumulated CO_2 emission (g) for each traffic light crossing (1500 m distant)

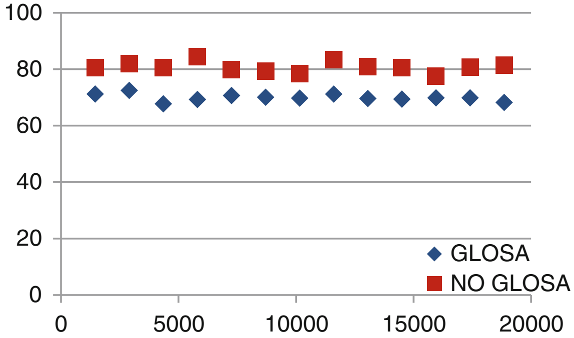


Figure 9 shows the cumulated CO_2 emission for a 1500 m distance travel containing a traffic light to cross, with a maximum speed of 50 km/h. It shows the same behavior for each crossing of the traffic light with and without GLOSA system.

For this situation, the average gain in terms of CO_2 emission reduction, with the GLOSA system, is 13 %.

Other tests have been performed with different synchronizations between both traffic lights, chosen randomly.

Compared to the first situation tested, this change had increased the stop time duration, but it did not have a significant effect on the gains obtained with the GLOSA system: the average gain for these different situations is: 12 %.

The whole gain for the set of measures on the described situations with a maximum speed limit of 50 km/h is 13 %.

A second type of situation was tested, with a 70 km/h speed limit. The results obtained show a gain in CO_2 emission reduction of 14 %.

The average reduction of CO_2 emission for the whole set of measures in the described situations is 13 % in the 1500 m trip in which there was a traffic light to cross.

4.5 Analysis

The results obtained show a high gain in CO_2 emission reduction, but this is to be compared to the length of the trip: 1500 m, and the fact that the environment can be considered as a straight line with no other vehicles.

Thus, it shows an interesting way reducing CO_2 emission when handling intersections. The measures only concerned one vehicle equipped with the GLOSA system.

5 Conclusion

In this paper a GLOSA system implementation has been presented with experimental results for the evaluation of the gain in terms of CO_2 emission reduction. The first results are promising.

In order to more precisely qualify the system, the travel time with the GLOSA system has to be evaluated. It would be interesting to evaluate the gain for several vehicles with various penetration rate of the GLOSA system including the impact that could have on non equipped vehicles creating a “Green Light Platoon”.

The impact in terms of user experience and acceptance is also to be studied even for non equipped road users impacted by the system.

GLOSA is only one feature using the potential of Cooperative Traffic Lights. Actors of the deployment of V2X communication also foresee other use cases with Cooperative Traffic lights, such as Red Light Signal Violation [7] or Green Phase Request for emergency vehicles.

Extended features of Cooperative traffic lights may also enable Adaptive Route Change [8] with traffic data communication in addition to other non specific features of ITS Road Side Units.

Cooperative automated vehicles will also benefit from the deployment of Cooperative Traffic Lights for redundancy information to handle intersections.

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Upgrade-E: A Rapid Prototyping Platform for Connected Powertrain Functions and Services

A. Engstle, A. Zinkl, A. Angermaier and W. Schelter

Abstract The AVL software package "upgrade-E" enables the predictive calculation of the expected speed, elevation and tractive power requirements of an unknown driving route. The development platform mainly accesses freely available data formats such as Open Street Map (OSM) and SRTM altitude profiles. The predicted driving route provides a plethora of optimisation possibilities for classical vehicle and powertrain functions. The prototype version of the software is implemented in AVL's electric vehicle Coup-e 800 and runs on a conventional 7-inch tablet PC with appropriate data gateways to the vehicle's CAN bus.

Keywords Connected powertrain · Vehicle-to-x · Predictive energy management

1 Introduction

Buzzwords like "Vehicle-to-x" and "connected powertrain services" are currently on the mind of most decision takers in automotive as well as in heavy duty industry. The basic question, how navigation data, internet- and infrastructure-information can be utilized in order to optimize fuel efficiency, electric driving range etc. and how these information can be bundled to provide additional services to the customer/driver are keeping the strategic departments of the OEMs busy.

The biggest issue of this thematic constellation however consists in its interdisciplinary multi-domain nature. Therefore it is quite difficult and cost-intensive to test new "connected-functionalities" as it implies the involvement of trans-sectoral departments and suppliers. For this reason AVL has developed a rapid prototyping platform for connected powertrain services which runs on a conventional 7-inch tablet PC with appropriate data gateway to the vehicle's CAN bus. The software

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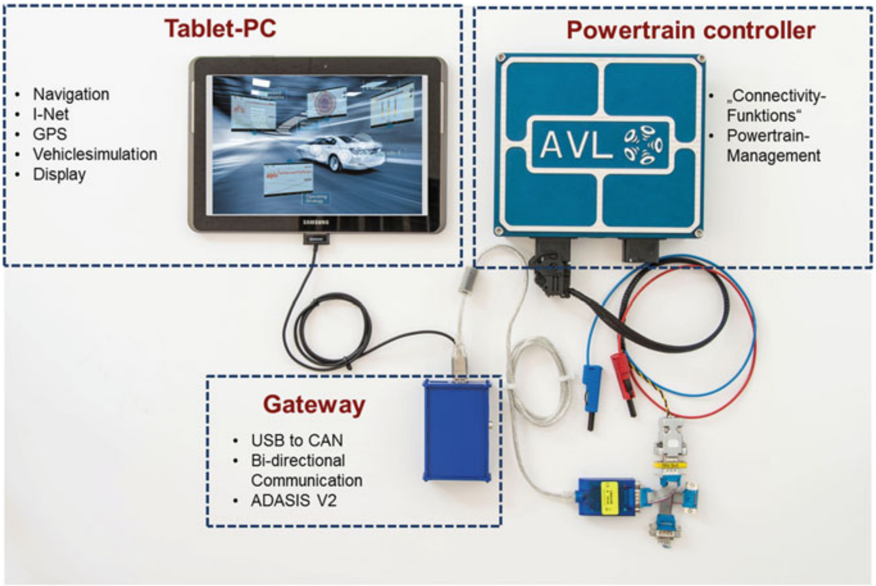

Fig. 1 Rapid prototyping platform “upgrade-E”

package “upgrade-E” (compare Fig. 1) enables the predictive calculation of the expected speed, elevation and tractive power requirements of an “unknown” driving route. The development platform exclusively accesses freely available data formats such as Open Street Map (OSM) and SRTM altitude profiles in order to be independent of a supplier.

2 Basic Idea Upgrade-E

The idea of using driving route prediction in order to optimize fuel consumption by adjusting the calibration of a powertrain and designing new predictive-functions is well known. Especially for electrified powertrains with more than one traction source those predictive approaches appear quite attractive as they offer a substantial increase in fuel efficiency by adjusting the operating strategy of the combustion engine and the E-Motor to the respective driving task.

But also conventional powertrain concepts can be improved. Using predictive information for controlling the emission aftertreatment systems of a conventional truck, especially the Diesel Particulate Filter (DPF) for example offers a significant potential in fuel economy reduction. From time to time the DPF requires an active regeneration, which removes the particulates from the filter, at the cost of fuel. By telling the DPF-function at which point of time a full-load situation is most likely to occur within the next 100 km the system performance can be optimized over the expected duty cycles.

Finally the calculation of the traction power over the expected driving profile can be utilized for spanning the electric range display of an electric vehicle/plug-in electric vehicle. All surveys concerning electro mobility show that an inadequate range is given as the biggest disadvantage of electric vehicles. Apart from an increase in range, the precise representation of the remaining range is one of the possibilities to reduce range-anxiety and hence increase acceptance by the customer.

3 Quality Criteria

The prerequisite for gaining an energetic advantage is that the calculated driving profile closely matches the real route driven later as much as possible. Three criteria have been introduced to evaluate the quality of the speed, elevation and tractive power requirement profile:

- Input data: How well does the predicted speed/elevation profile match the driven route?
- Simulation: How well does the simulated power profile correspond to the measured power requirement of the vehicle?
- Calculation time: How long does the system need to predict the energy requirements for a 100 km route?

The quality criteria "calculation time" is affected by increases in the degree of detail provided for the input data and also with increases in simulation precision. Since the calculation time represents a critical factor for the customer (the customer does not want to wait several minutes for the electrical range to be displayed), there is in principle the possibility of relocating the complete process of data preparation to an external IT centre and not running the calculations "onboard" in the vehicle. The software package "AVL upgrade-E" can be used in both scenarios (onboard and backbone). Since calculation in the vehicle has advantages relating to data privacy and fail-safe operation if there is no network coverage, the prototype version employed the onboard variation.

Figure 2 shows the two-step layout for the evaluation of predictive energy management systems. While the lower function section (creation of vehicle profiles) is identical for all powertrain concepts (PHEV, REX, EV), the optimization of the (customer) functions is heavily dependent on the powertrain concept. The "bottom line" added value of predictive energy management is either the increase in the electrical range or the decrease in fuel consumption.

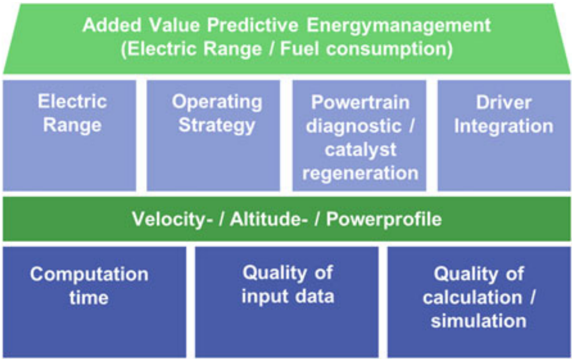

Fig. 2 Quality criteria predictive energy management

4 Software Concept Upgrade-E

The energy consumption of (electrified) vehicles is not only affected by the vehicle speed profile (calculation of the main road load factors) and the elevation profile (calculation of the road gradient effect on road load), but also significantly by the power requirements of auxiliary components. The predictive energy management system predicts the power requirements of the auxiliary components over time by using current data—read via CAN—concerning the auxiliary components (windscreen wipers, lights, aircon compressor, etc.), the external temperature and the desired internal temperature.

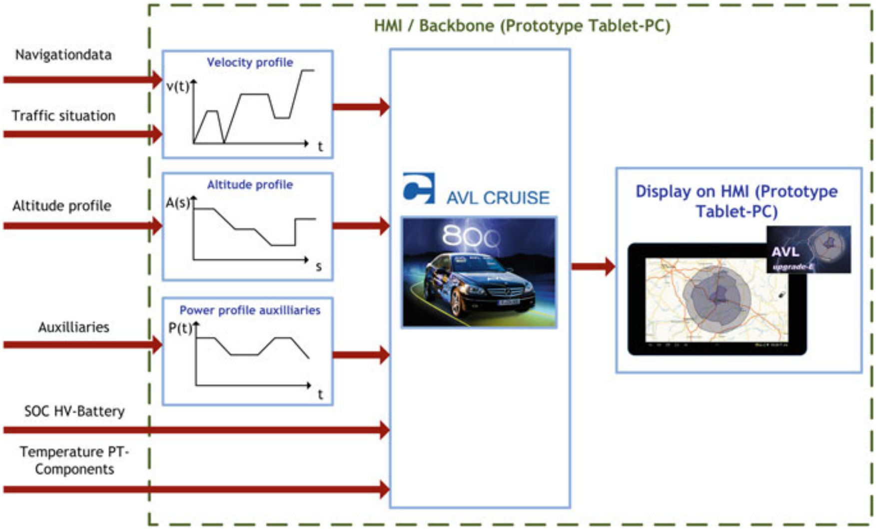

Fig. 3 SW-architecture upgrade-E

The current state-of-charge of the battery storage is read continuously from the vehicle CAN at a sample rate of once per minute, compared with the simulated value and if necessary, transferred as a new initial value into the simulation environment. In order to consider the performance capacity of the electrical drive components, the temperature of the components (e-motor, inverter, HV battery) are also taken into consideration in the simulation environment. The complete software architecture and the process of data preparation, simulation and visualization on the vehicle HMI (the prototype is on a tablet PC) is shown in Fig. 3. The vehicle used in the trials to test the functions was the AVL electric vehicle "Coup-e 800" [4].

5 OSM Navigation/SRTM Elevation Data

The map data in navigation systems is stored in the form of nodes and ways. Nodes are defined by latitude and longitude and represent route points where a change of direction occurs or could occur. The nodes themselves are connected by ways that contain information pertaining to the distance between the nodes and the road class (country road, highway, etc.). In order to be able to derive the most realistic speed profile possible from the map data, the available average speed data for each way is connected in a speed-distance diagram. Taking driver characteristics such as sporty, comfortable etc. into account, the acceleration and stationary times can subsequently be considered and the speed-over-distance profile can be transferred to a speed-over-time profile (compare Fig. 4).

The resulting velocity profile needs to be modified and enhanced with up-to-date information concerning the traffic situation and traffic flow. Commercial traffic situation service providers evaluate the GPS signals of active navigation devices and use the data to determine the speed of traffic flow on the roads. Since the initial

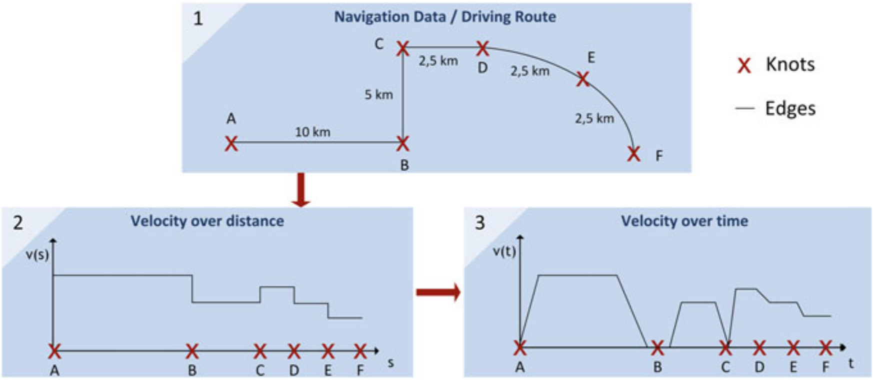

Fig. 4 Processing of map data into velocity profiles

speed profile was generated via distance, the VPG can include the additional information from the traffic flow service, which is available as v(s), into the speed profile.

For calculating the elevation profile freely available data from the “Shuttle Radar Topography Mission” (SRTM altitude information) are processed into an altitude over distance characteristic.

6 Simulation

For calculating the tractive power requirements for the calculated profiles (velocity over time/altitude over distance/electric power over time), the powertrain and on-board electrical system architecture of the respective vehicle is modeled in the 1d simulation tool “Cruise” which is compiled for the tablet PC’s ARM processor (Snapdragon).

The powertrain simulation tool “Cruise” contains calculation components for the main road load components, the on-board load, all inertias and loss mechanisms (friction, component losses, warm-up behavior, etc.). Simultaneously, Cruise permits a comfortable and modular adaptation of any arbitrary powertrain architecture and possible component variants.

7 Variance in Energy Consumption

Before an evaluation of the quality of the algorithm can be carried out, it is necessary to investigate how the energy consumption of the (electric) vehicle varies when driving the same route many times under similar traffic conditions. Figure 5 shows the speed profile for a route that was driven twice with identical boundary conditions (driver, time of day, traffic situation). The driver was given the task of keeping as close to the speed limits as was reasonable.

The circular route with a distance of approximately 28.3 km was completed the first time in a time of 2,420 s (average speed 42.2 km/h), the second time in 2,544 s (average speed 40.0 km/h). While the energy consumption of the electric vehicle was measured at 5.75 kWh for the first trip, the second trip required 5.55 kWh. This means that the energy consumption in this case fluctuated by approximately 3.5 %.

Even when considering this investigation represents a snapshot and would need to be supported by wide-ranging statistical analysis, it still provides a (first) indication in which range the energy consumption of an electric vehicle can vary under favourable boundary conditions.

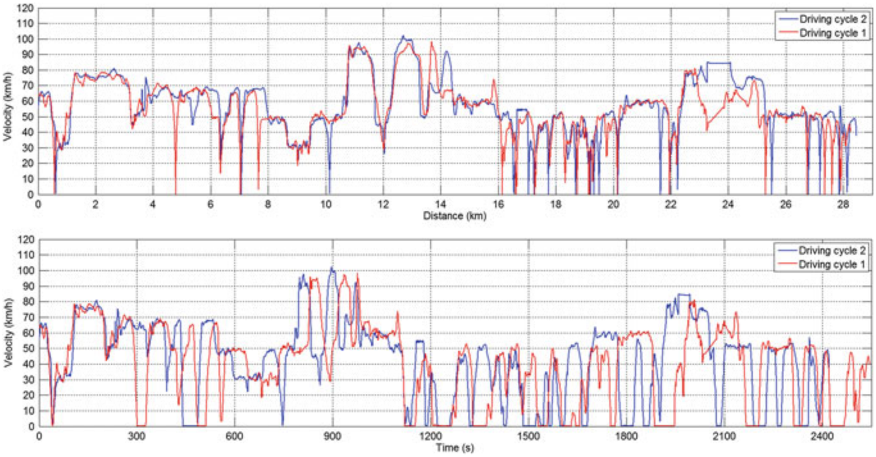

Fig. 5 Comparison of speed profiles for the same route profile and similar boundary conditions

8 Quality of the Drive Profiles

Figure 6 compares the speed and the elevation profiles between actually driven route and the predicted result for a second, somewhat faster circular route with significant changes in elevation. The route covered approximately 37.7 km and the trial was completed in 1,866 s (average speed 72.7 km/h), the predicted drive time was 1,947 s (average speed 70.0 km/h). The correlation of the speed traces over the

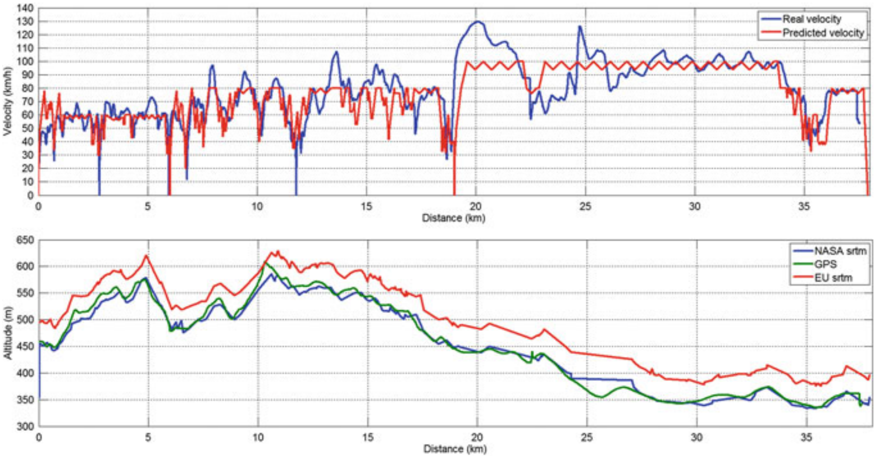

Fig. 6 Comparison of real/predicted speed/elevation profile

route can be assessed as “useful”, as long as the driver keeps to the speed limits. Deviations due to overtaking maneuvers (refer to 20 km) cannot be anticipated by the prediction.

In contrast to the difference, irrelevant from an energy point of view, between the absolute elevation data, the qualitative profiles for all three input formats (SRTM USA and EU, GPS elevation meter) match closely. The energetic sensitivity of all three traces can be simulated to <0.2 kWh (<1 % SOC).

9 Quality of the Simulation

Figure 7 compares the powertrain’s tractive power and the resulting SOC of the electric vehicle with the calculated/predicted values. The real energy consumption of the electric vehicle (without recuperation) was 7.14 kWh, compared to a simulated value of 7.2 kWh. Although the practically exact correlation in the energy consumption, after close scrutiny, must be interpreted as a favorable conjunction of mutually compensating effects, wide ranging evaluations do result in the conclusion that the quality achieved by the simulation is in the same order of magnitude as the variance in energy consumption observed during repeated driving of the same route.

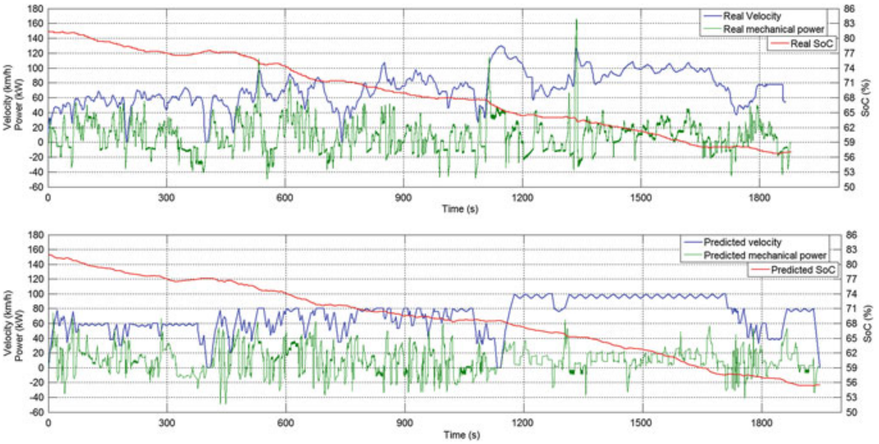

Fig. 7 Comparison of measured tractive power and SOC of the real speed profile/elevation profile with the simulation results for predicted speed/elevation profile

10 Conclusion

Within the scope of currently intensive but unstructured discussions surrounding the Vehicle-to-X/Connected Powertrain topic, the precise prediction of elevation, speed and tractive power requirements provide an interesting possibility to implement potential energy savings.

The modular vehicle simulation software Cruise enables the simulation model to be comfortably adapted to widely different powertrain concepts and permits the on-board calculation of tractive power requirements for both passenger cars and commercial vehicles with reasonable calculation speed. Implemented on a conventional tablet PC with navigation system, altitude information and CAN-Gateway upgrade-E realizes a unique and cost-efficient rapid prototyping platform for connected powertrain services.

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Highly Efficient Electrical Recuperation System

B. Boucly and H. Perseval

Abstract PSA Peugeot Citroën has unveiled in 2013 a new hybrid powertrain concept—Hybrid Air-described as a disruptive hybrid system that makes a major step to lower emissions and fuel economy. With this system during city driving cycle, vehicle operates in Air Mode from 60 to 80 % of the time. As thermal engine operation is resultant of this on and off mode, the alternator is mainly shut off; in consequence, the lead-acid battery has strong cycling increase and can be quickly damaged. Besides, it's not suitable to power the electrical equipment during such a long time with only battery voltage (lower than 14 V). To fit those requirements, PSA Peugeot Citroën has developed an electrical system called "SPRESSO" performing two major functions: quick storage and energy management. It can handle with high efficiency, the charge and the discharge of a high-capacity electric double layer capacitor (EDLC), minimizing spare stored energy and makes it possible to supply electricity to all vehicle equipment during Air Mode. SPRESSO is compatible with standard 12 V architecture (alternator and lead-acid Battery) and offers a long life and cost effective electrical system to Hybrid Air equipped vehicles.

Keywords SPRESSO · Hybrid air · 12 V Electrical recuperation · Coasting

Glossary

EDLC	Electrical Double Layer Capacitor
ICE	Internal Combustion Engine
EEHE	Electric and Electronic Systems in Hybrid and Electrical Vehicles and Electrical Energy Management

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1 Introduction

PSA Peugeot Citroën has developed an all-new technology combining Gasoline internal combustion engine and compressed air storage. Hybrid Air-described as a disruptive hybrid system that makes a major step to lower emissions and to the path towards fuel consumption of 2 l/100 km.

Hybrid Air system uses an electronic management system that adjusts independently to one of three modes: air (Zero Emission Vehicle), Gasoline, Combined.

This technology uses an innovative combination of tried and tested technologies: compressed air for energy storage rather than batteries, an hydraulic pump-motor that recovers energy generated by the ICE and from braking and deceleration, storing it in a compressed air energy storage, and automatic transmission offering quality, smooth and pleasant drive (Figs. 1, 2 and 3).

The hybrid car needs two specific requirements:

- 55 Wh minimum storage energy to offer low fuel consumption.
- 30 KW power at least, to perform the vehicle dynamic and to recover energy with high efficiency.

Hydraulic system is suitable to offer high power but must be designed to target energy requirement.

Fig. 1 Hybrid air car

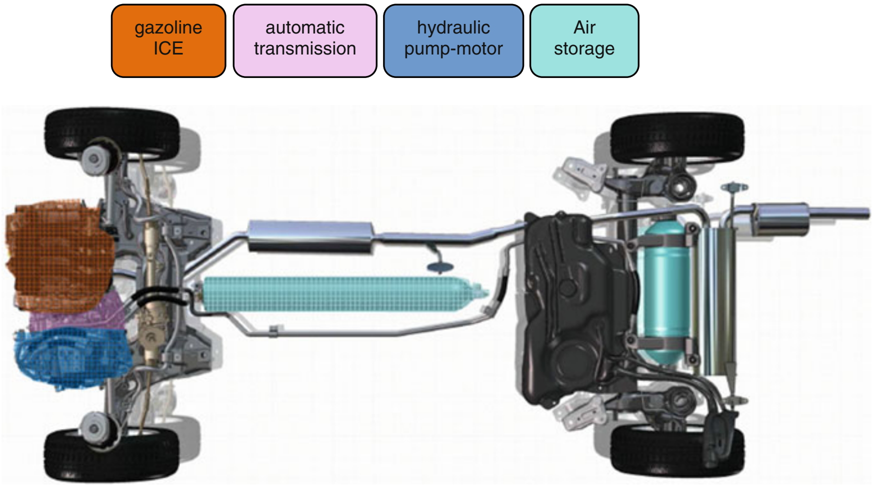


Fig. 2 Hybrid air system components

Fig. 3 Power and energy need and achieved values for different full hybrids concepts

	ENERGY	POWER
TARGET	55 Wh	30 KW
HYDRAULIC	55 Wh	60 KW
ELECTRIC	600 Wh	30 KW

2 Electrical System Architecture

2.1 Electrical Background

As a result of the system requirements, with Hybrid Air system during city driving cycle, vehicle operates in Air Mode (ZEV) from 60 to 80 % of the time. As thermal engine operation is resultant of this on and off mode, the alternator is mainly shut off during a time range up to 2 min.

Those requirements are very similar to coasting needs.

By using a 12 V conventional electrical architecture, the lead-acid battery has strong cycling increase and can be quickly damaged. Besides, it is not suitable to power the electrical equipment during such a long time with only battery voltage (lower than 14 V) (Fig. 4).

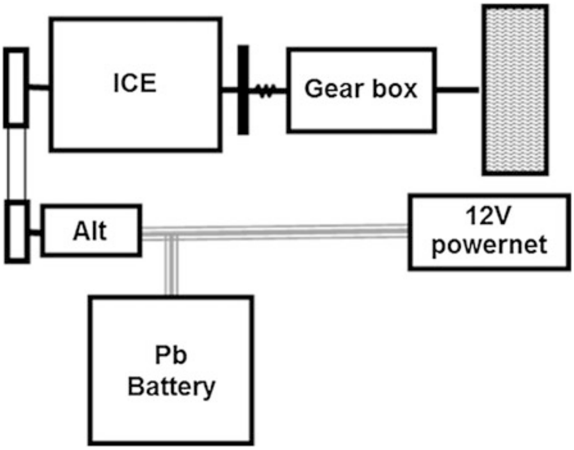


Fig. 4 Conventional 12 V electrical architecture

2.2 *SPRESSO System*

To fit those requirements, PSA Peugeot Citroën has developed an electrical system called “SPRESSO” performing two major functions:

- quick electrical storage
- electrical energy management.

It can handle with high efficiency, the charge and the discharge of a high-capacity electric double layer capacitor (EDLC) (Fig. 5).

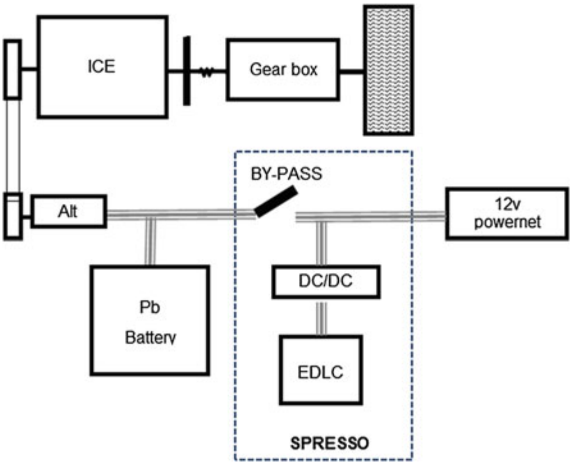


Fig. 5 Hybrid air electrical architecture

2.3 Description

The system features a power-switch BY-PASS, an 1.8 kW reversible DCDC converter, a 30 kJ EDLC storage. These capacitors can't hold energy as long as batteries, but they are great at rapidly charging and discharging, even at low temperature (−10 °C). The converter is able to charge and discharge the capacitors from 5 to 12 V, at a limit current of 150 A (Fig. 6).

2.4 Gasoline Mode

The by-pass switch is turned ON. As ICE is running, the alternator is operational and supplies a current to the battery, to the 12 V powernet and to the converter as well. The converter is charging the EDLC storage up to 12 V (Figs. 7 and 8).

2.5 Air Mode

The by-pass switch is turned OFF. As ICE is OFF, the alternator is not operational and do not supply any current. The converter is now discharging the EDLC storage from 12 to 5 V providing a relevant voltage stabilization compliant to the powernet loads (Figs. 9 and 10).

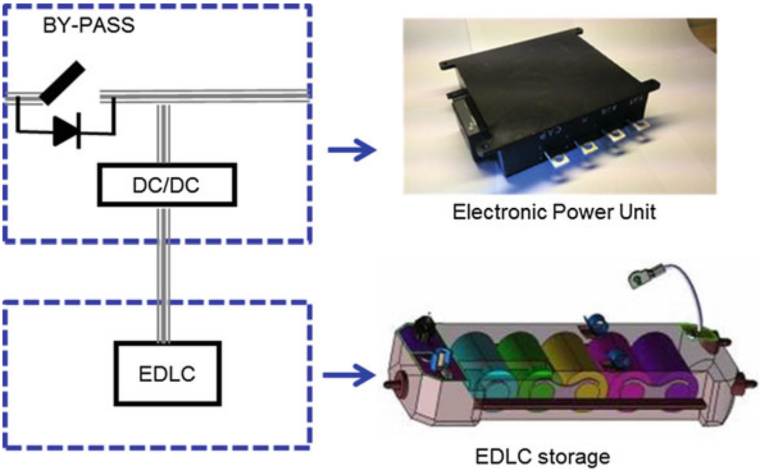


Fig. 6 SPRESSO description

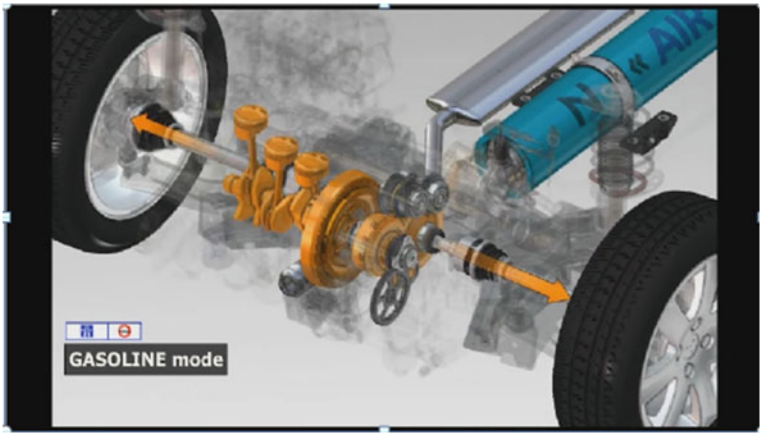


Fig. 7 Mechanical system in gasoline mode

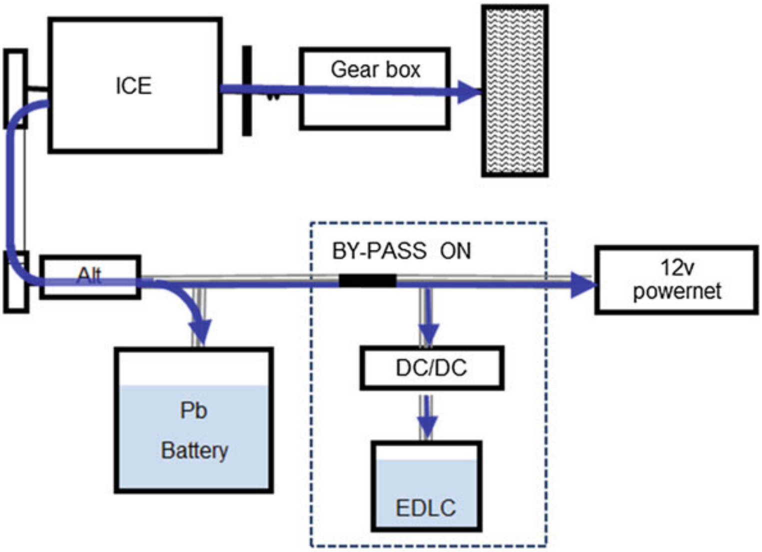


Fig. 8 Electrical system in gasoline mode

2.6 Combined Mode

The by-pass switch is turned OFF. As ICE is ON, the alternator is operational and charges the battery at a low current level. The converter is discharging the EDLC storage from 12 to 5 V providing a relevant voltage stabilization compliant to the powernet loads (Figs. 11 and 12).

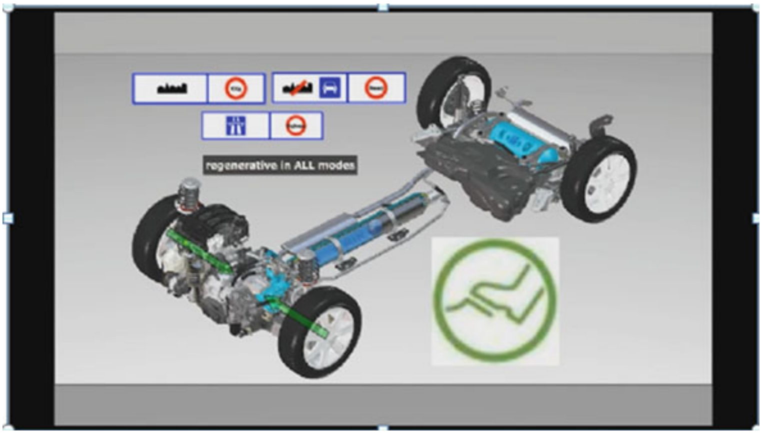


Fig. 9 Mechanical system in air mode

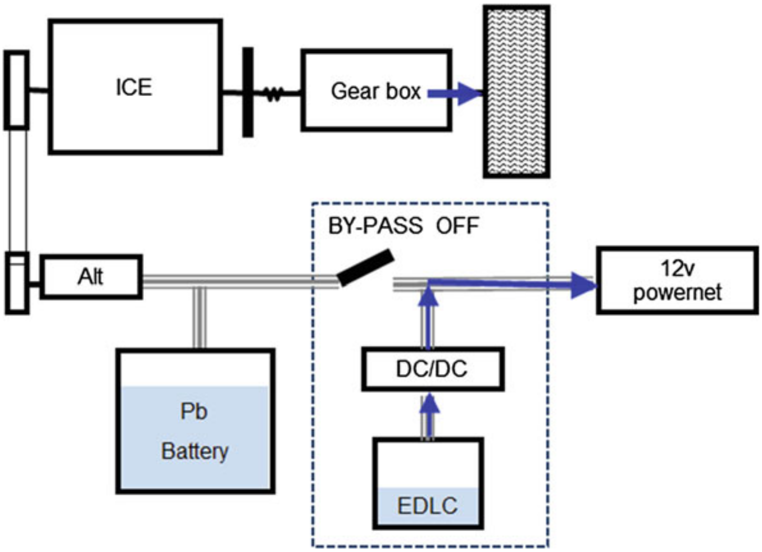


Fig. 10 Electrical system in air mode

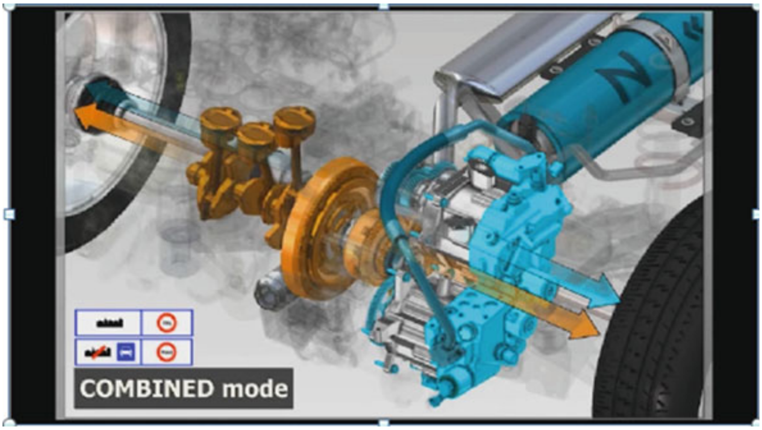


Fig. 11 Mechanical system in combined mode

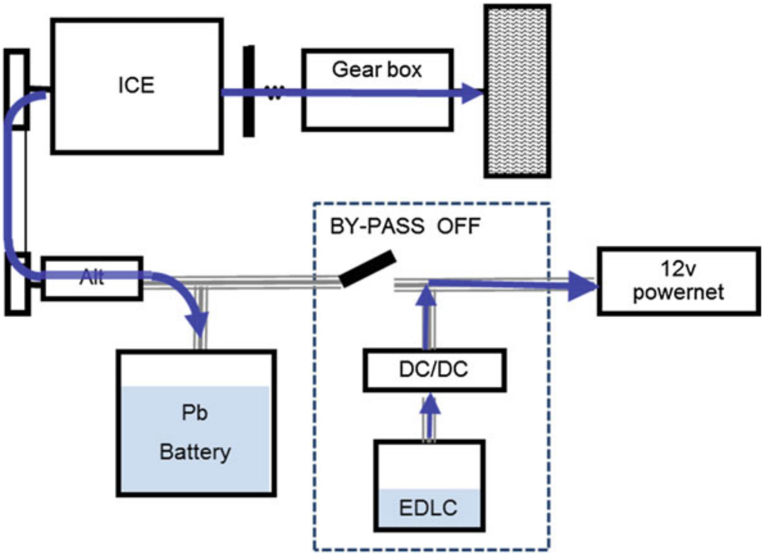


Fig. 12 Electrical system in combined mode

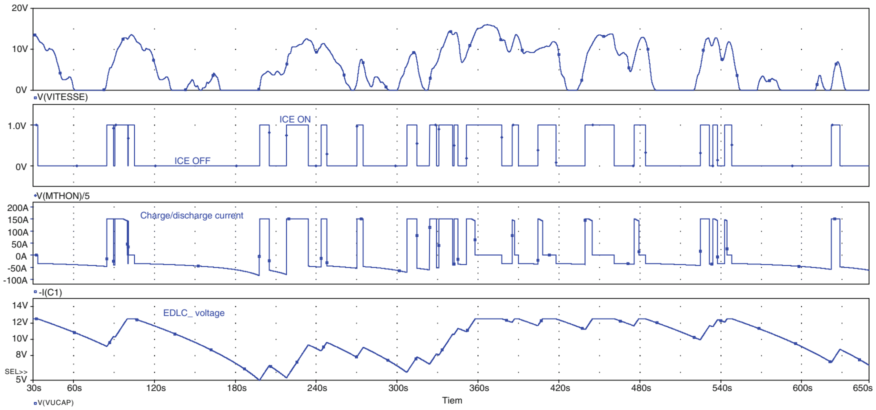


Fig. 13 Electrical behaviour on road driving test

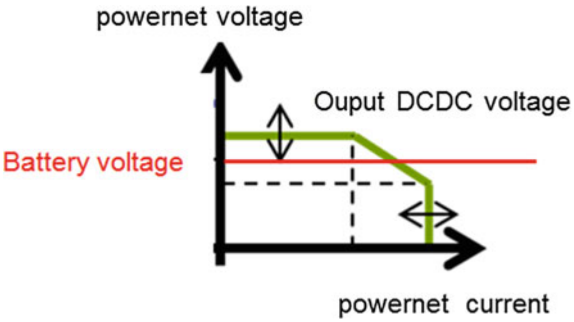


Fig. 14 DCDC converter scalability

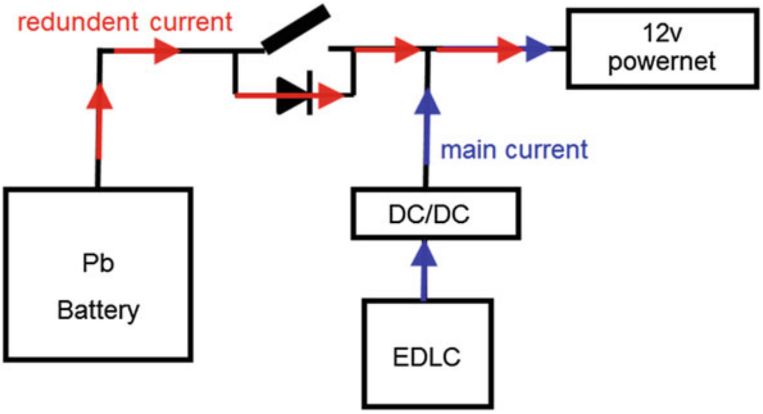


Fig. 15 Safety concept

3 Electrical Behaviour

3.1 Road Driving Test

With only 30 kJ storage energy, the device is able to supply 30 A to the powernet loads for a long time (Fig. 13).

3.2 Compliance to Safety Goals

Input and output current and voltage of the converter are independently scalable by internal design. Due to the safety diode on the by-pass, the loads current can be supplied by two different sources: Pb battery and converter. By this way, on air mode, this driving scenario is safe, and in compliance to ISO 26262 goals (Figs. 14 and 15).

3.3 Storage Modules Challenge

The main issue of the development was to store electricity as efficiently as possible, with minimum weight, volume and cost.

Furthermore, the other issue is to prolong the life span of the lead acid battery. On Hybrid air system, the average current flowing in the battery is lower than the

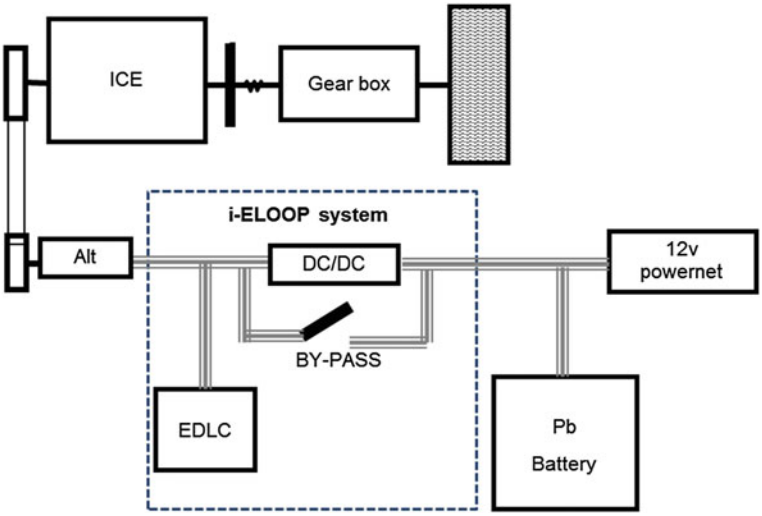
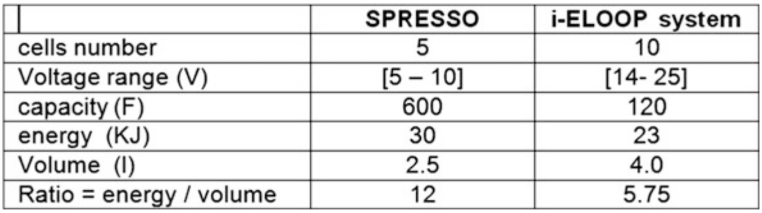


Fig. 16 i-ELOOP system



	SPRESSO	i-ELOOP system
cells number	5	10
Voltage range (V)	[5 – 10]	[14- 25]
capacity (F)	600	120
energy (KJ)	30	23
Volume (l)	2.5	4.0
Ratio = energy / volume	12	5.75

Fig. 17 Storage module challenge

current of an AGM type battery used on conventional stop-start electrical architectures. A low cost and standard liquid lead battery can be suitable.

By the way, the ratio energy/volume must be as high as possible, as we look at different architectures (Figs. 16 and 17).

4 Perspectives

SPRESSO system offers a low cost effective solution to coasting applications. Thanks to its voltage and current monitored converter, the powernet voltage can be hold at safety rates (14 V), and other technologies are suitable to the storage module (Ni-Mh, Li-ion) as well.

5 Conclusion

PSA has developed a disruptive hybrid system including a major electrical technology (SPRESSO).

It is compatible with standard 12 V architecture (alternator and lead-acid Battery) and offers a cost effective electrical solution to enhance stop-start and coasting applications.

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Part VII
Key Technologies for Modern Cars

Distance Measurement Using Near Infrared Sensors

Bernold Rix, Andreas Nebeling and Tycho Raab

Abstract Advanced Driver Assistant Systems (ADAS) are constantly improving in performance and fitment rates in modern cars. While in the past parking aids have been a driver's selection for a price premium, today most vehicles offer park distance control as a standard configuration. When developing driver assistant systems it is important to select the most suitable technology. Parking aids for instance typically rely on ultrasonic or camera sensors. In premium cars a combination of both sensor technologies is implemented to improve the system reliability and at the same time increase the user's benefit. A single CMOS imager camera cannot measure the distance of an object but an image is a good method to interact with the driver. Hence, the fusion of sensors results to more sophisticated systems. The availability of multiple assistant systems in a vehicle will ultimately lead to autonomous driving. Today, autonomous or semi-autonomous driving is used for low-speed parking maneuvers. Mainly undefined legislation framework is slowing down a wider adoption rate. Recently US government has lowered the requirements for self-driving vehicles. Can autonomous cars be sold as soon as 2015? This paper reviews different sensing technologies for driver assistant systems, highlights the benefits and necessity of sensor fusion and presents an optimized approach for utilizing infrared time-of-flight (TOF) sensors to implement cost efficient, reliable, scalable and precise environmental sensing for driver assistance and comfort applications.

Keywords Infrared · Time-of-flight · 3D sensor · HALIOS® · Distance measurement

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1 Introduction

Advanced Driver Assistance Systems (ADAS) require smart sensors. Selecting the right sensor technology or technology mix will directly define system performance, benefit and ultimately driver acceptance. Hence, it is essential to understand the different sensing technologies as well as its advantages and drawbacks.

When monitoring the vehicle's environment there are different optical sensing technologies such as microelectronic waves ($\lambda = 3 \ldots 30$ mm), ultrasonic sound ($\lambda = 5.0 \ldots 8.5$ mm) or modulated light ($\lambda = 900 \ldots 980$ nm).

Due to the specific wave lengths the different optical sensing technologies support different measurement ranges, resolutions and system cost points. Laser and radar technology are relatively expensive and are mainly used for long-range applications such as cruise control. Ultrasonic is an established technology for parking assistant. The focus of the paper is on infrared based optical sensors due to their significant technical potential for automotive applications (Fig. 1).

1.1 Triangulation

For triangulation at least two optical systems are needed. The distance of both must be known as well as their angles to each other. A passive approach is realized when both optical systems are cameras. For an active approach one of the optical systems is a light source e.g. a laser and the second source is a camera.

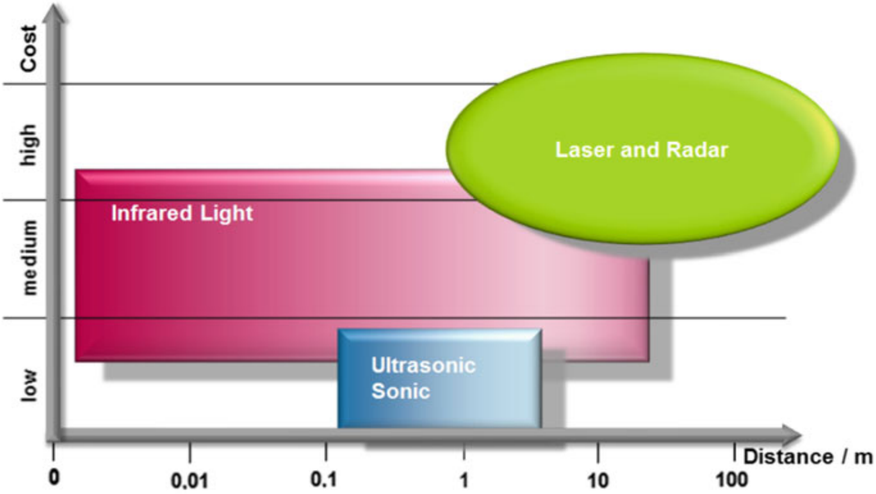

Fig. 1 Measurement technologies versus costs

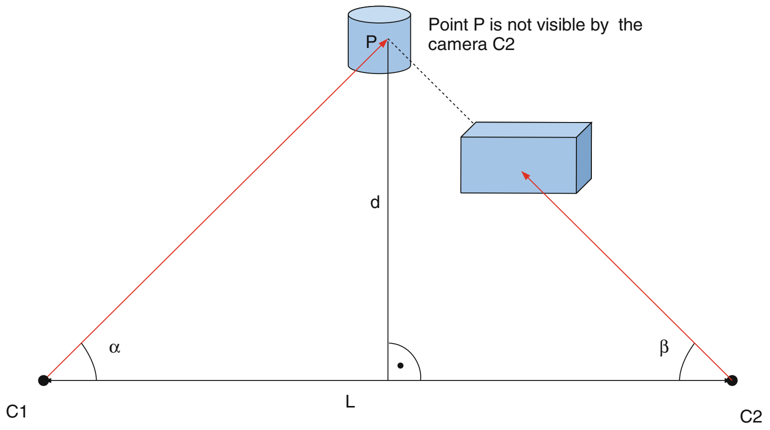

Fig. 2 Triangulation with shadow failure

In an active approach illumination and observation directions can be collinear which reduces failures due to shadowing. But for a 1D or 2D measurement the object has to be scanned which is time consuming and increases the complexity of the optical system because of moving parts like mirrors etc.

Both systems have in common that a high calculation performance is needed for the signal processing due to their high data rates (Fig. 2).

1.2 Interferometric Approach

Another approach is to use structured light to illuminate the scenery instead of scanning it. That is much faster because the time for scanning is dropped. The critical point is the light source which must have a constant spatial phase because only coherent light shows the needed interferences.

1.3 Travel Time Measurement

Especially in the automotive area distance measurement is based on Time of Flight (ToF) measurement like radar, laser, ultrasonic and infrared light.

In terms of robustness, speed and costs the infrared light is one of the most promising technology. It is used for pure distance measurement (1D) and for 3D cameras as well.

For illuminating the scenery usually infrared light ($\lambda = 910–980$ nm) is used. It has the advantage that it is not visible for the human eye and a wide range of LED types and manufacturers are available.

Two main proceedings are established on the market.

- Continuous Wave (CW)
- Pulse Modulation (PM)

In the following an infrared time-of-flight signal conditioner will be presented which is manufactured in a cost efficient standard CMOS process. It meets the automotive requirements in terms of robustness (ambient light suppression), speed and cost.

2 3D Light Pulse Travel Time Sensor

In this approach a light pulse with energy E_0 is used to obtain a 3D picture of a scenery by camera with a very short shutter. The reflected pulse receives the photo diode array superimposed with the ambient light E_{AL} with the energy E_{REC} (Fig. 3).

The width of the light pulse is quite short with 30–60 ns and also the shutter times are in the same range of 10–100 ns. Due to the short pulses, even when a high accumulation rate is chosen, the power consumption is smaller in comparison to the Continuous Wave approaches.

Figure 4 shows the timing of the shutter.

At time t_0 a laser light pulse E_0 of length T_P is send to the 3D scene.

The 1st measurement of the reflected light ends when the laser pulse stops. The 2nd measurement starts at the same time when the 1st shutter is closed. Both

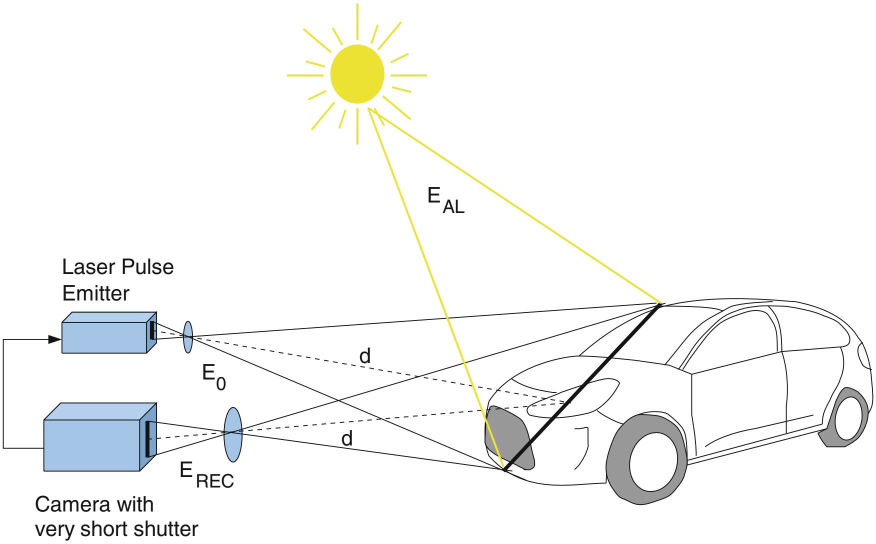

Fig. 3 Measurement technologies versus costs

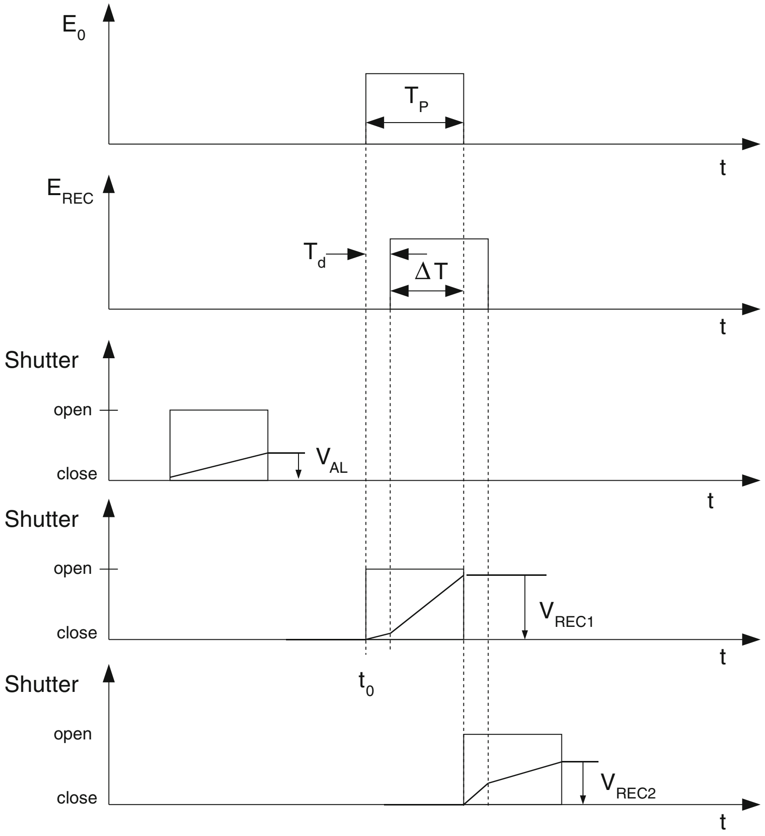

Fig. 4 Measurement technologies versus costs

integrated charges contain also a portion caused by the ambient light (E_{AL}). That portion is measured with the shutter time Tp when the laser is shut off and is subtracted from the charges V_{REC1} and V_{REC2}.

The collected photon during each measurement causes a voltage which can be expressed by

$$V_{REC1} = R * O_R * \tau * (E_{AL} T_P + E_0 * \Delta T) \tag{1}$$

$$V_{REC2} = R * O_R * \tau * (E_{AL} T_P + E_0 * T_d) \tag{2}$$

With R is the responsivity, O_R the reflectivity of the object and τ the transmission coefficient of the optic.

After subtracting the ambient light portion and with

$$\Delta \mathrm{T} = \mathrm{T_P} - \mathrm{T_d} \tag{3}$$

one yield:

$$\frac{V_{REC1}}{V_{REC2}} = \frac{T_p - T_d}{T_d} \tag{4}$$

with

$$d = \frac{c}{2} T_d \tag{5}$$

the distance equals

$$d = \frac{c}{2} \frac{V_{REC2}}{V_{REC1} + V_{REC2}} \tag{6}$$

The picture below shows some measurements with a photo diode array of 128 × 96 pixel. The photodiode are Lateral-Drift-Field Photo-Diodes (LDPD) with a very small pixel size of 40 × 40 μm manufactured in a standard CMOS process and additional process options for the photo diodes (Fig. 5).

The sensing element is a low doped n-well with a build in electrical field. The generated electrons are pushed to the floating diffusion (FD). The control gate CG and the transfer gate TX form the needed potential barriers to collect the electrons (Fig. 6).

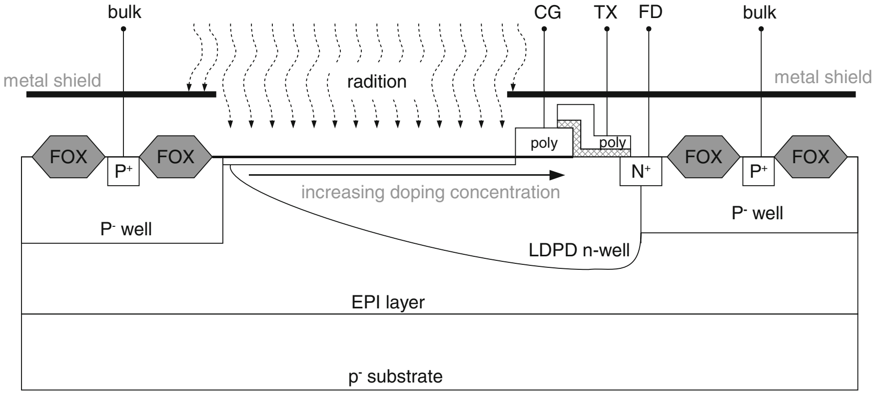

Fig. 5 Technology cross section of a LDPD

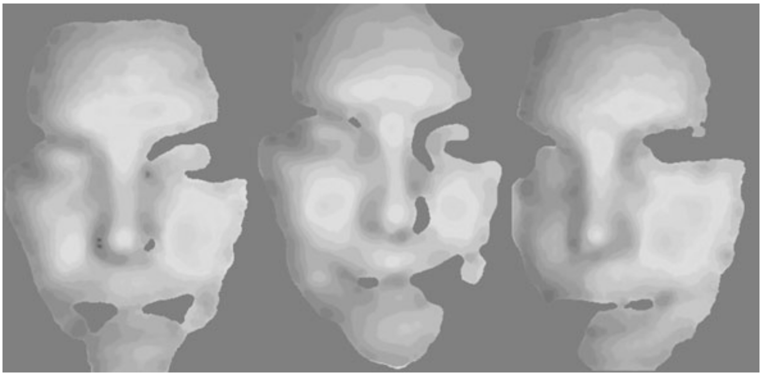

Fig. 6 3D Sensor measurement of a human face [3]

3 Halios IrDM

The new generation of infrared sensing is based on the HALIOS® (High Ambient Light Independent Optical System) sensor technology and the HALIOS® IrDM (Infrared Distance Measurement). The unique sensor principle is able to measure the reflectivity as well as the distance of an object in real time.

3.1 Features

- IR-based optical sensor not influenced by the targets degree of reflectivity. Enabling continuous distance measuring from 0 to 3 m with an accuracy of ±1 cm!
- Best ambient light immunity in the market! No weak components like PSDs (Position Sensitive Diode) used in triangulation based sensors or APDs (Avalanche Photodiode) used in laser based systems.
- One valid measurement result every 10 ms! IrDM is 3× faster than competitive sensors.
- Runtime adjustment: slower measurement = higher accuracy, faster measurement = better dynamics
- Eye safe applications: Normal and safe IR-LEDs, low current (max. 300 mA), pulsed signals (pulse length: 1 µs) and short burst measurements followed by long idle times. No additional mechanical protection required!
- Together with the features mentioned above, the well proven intensity based HALIOS® regulation is implemented. Two sensor principles in one are enabling stunning new applications!

3.2 Basic Functions

The function principle is based on the HALIOS® sensor technology reaching high ambient light immunity. The HALIOS® IrDM sensor is able to measure the reflectivity as well as the distance of an object independently. As shown in Fig. 7 the sensor function relies on comparing the sending light beam, which is reflected by the object to be detected, with a reference or compensating light beam. Both light beams are clocked in alternating manner. The intensity of both beams is regulated in order to have equal amplitude of sending and compensating light beam at the photo diode. The diagram below shows the case where both amplitude regulation and phase regulation are not settled. This means there is still a difference in the amplitude and the phase of sending—and compensating light beam (Fig. 8).

When the amplitude regulation has settled then the rectangular shape of the signal disappears. This situation is shown in Fig. 9.

Additionally the phase of both light beams have to be regulated in order to have exact 180° of phase shift at the receiver. This is not the case in the timing diagram above. The phase difference information is contained in the spikes shown in the first row of the timing diagram (amplified photo diode signal). The demodulator converts these spikes into a signal by using the phase demodulation clock. The regulator reacts on this input signal by shifting the phases as long as this signal information disappears. In the settled state shown in Fig. 10 the amplified photo diode signal looks like a noisy zero signal and the outputs of both regulators are containing the information of object reflectivity and distance.

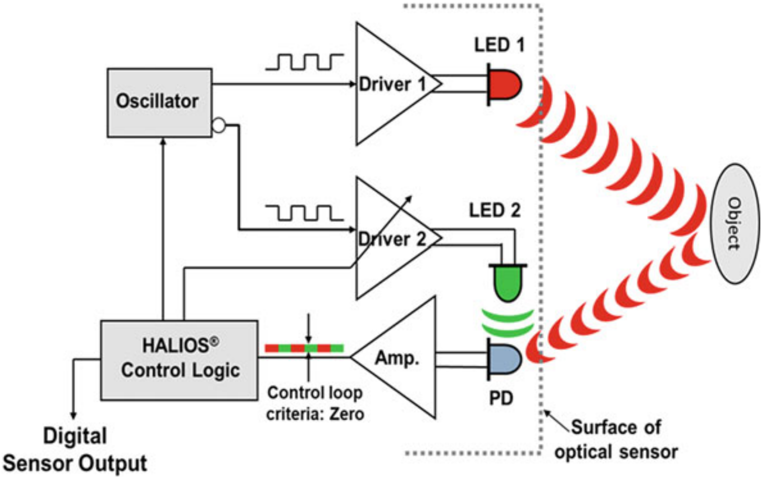

Fig. 7 HALIOS® principle

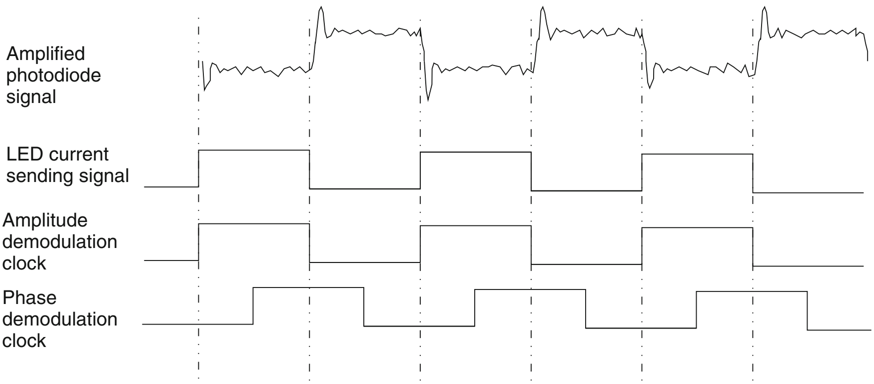

Fig. 8 Photo diode signal before amplitude and phase regulation

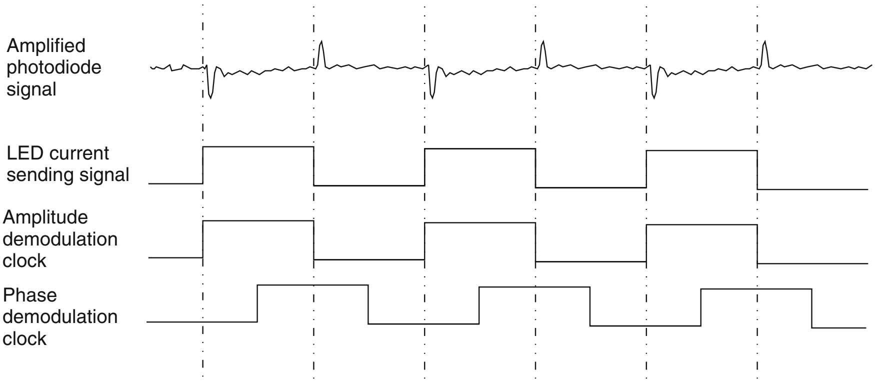

Fig. 9 Photo diode signal after amplitude regulation

3.3 Calibration

The calibration of ToF systems is very important subject since the used optical and electronic components are none ideal devices and therefore the generated and received signals differ from the optimal form.

3.3.1 Zero Calibration

The zero signal calibration is a measure to calibrate the individual variance of the modulator due to electrical and optical cross talk as well as synchronous

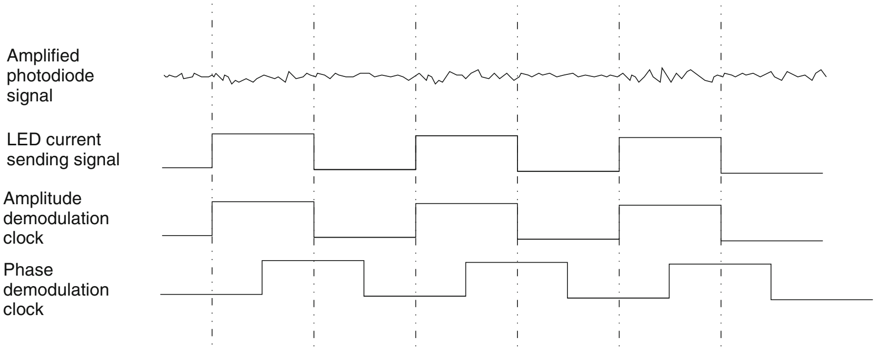

Fig. 10 Photo diode signal after amplitude and phase regulation

disturbances which can arise by EMC sources inside the sensor itself or by external sources.

Since the distance calculation is based on a phase shift measurement the phase of the sending current must be in line with the internal reference signal.

To determine these disturbances it is necessary to ensure that the sensor itself does not produce any optical signal. But at the same time the sensor should operate with full power to be able to measure also disturbances generated by the sensor itself. Especially the sending channel should be active because it is potentially a major source of disturbances. To suppress the optical signal the LED is bypassed by a dummy path with a resistor or a diode as load.

This measurement result can be readout by an external microprocessor who can adjust the normal optical measurements by tuning the T_offset of the compensator clock offset in steps of 9° at 1 MHz → 1000 ns/(360°/9°) = 25 ns and fine tune steps of 391 ps.

Part A of the Fig. 11 shows a phase shift Φ of the sending current signal. The integral over the sampling window yields a value greater zero since the sample window is not symmetrical in reference to the falling edge of the sending LED signal. When the integral equals zero the phase shift is compensated (part B).

3.3.2 Zero-Meter Calibration

The zero meter calibration is done by switching both DACs to the compensator LED output. By doing so the reference signal and the sending signal are using the same LED. Thus the optical path for both light beams is identical and the measurement result is a reference for the 0 m point of the sensor. So any differences in the electrical paths, sending and compensating, can be adjusted.

The measurement result can be readout by the controlling microprocessor and is available as a reference for further distance measurements.

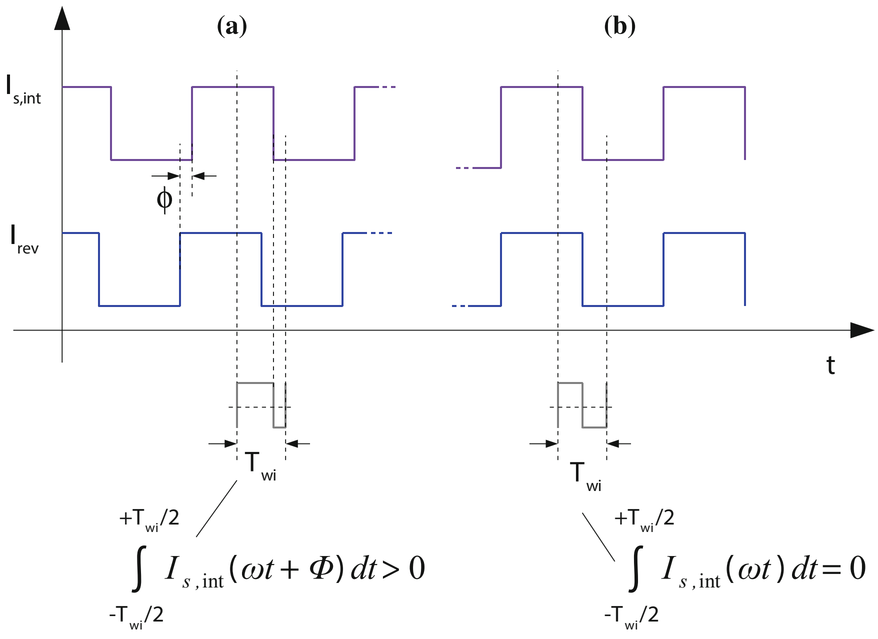

Fig. 11 Zero calibration

3.3.3 Modulator Calibration

The modulator calibration is done by analysing the DAC modulators at different operating points. This is done by operating both DACs with different coupling factors with the help of two electrical feedback networks.

For each coupling factor the deviation from the ideal value is a measure for the correction value. By measuring this value for different coupling factors it is possible to get a calibration curve. It shows the phase error as a function of the regulation amplitude. With this information a microprocessor can then make a correction of the optical measurements.

3.4 Measurement

The Fig. 12 shows the distance measurement (red curve) of two objects at a fixed distance of 145 cm. The blue curve is the DAC value of the amplitude representing the reflectivity. Changing the reflectivity has no impact on the distance value which has an accuracy of ±10 %. Only a slight increase of the noise can be seen when the reflectivity of the object of 10 %.

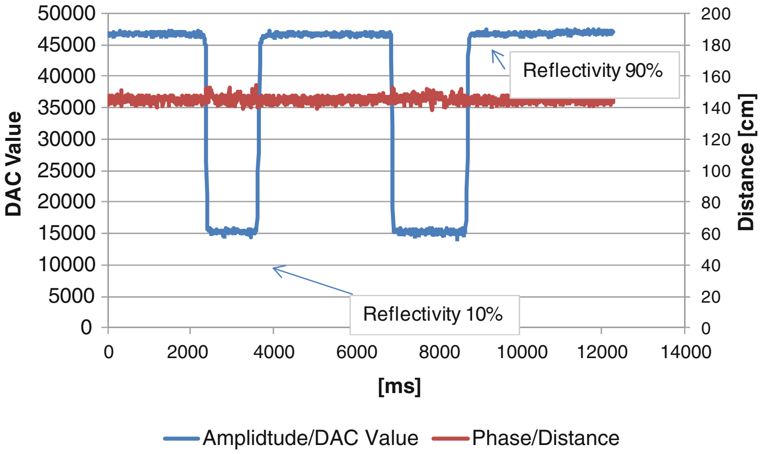

Fig. 12 Distance measurement of objects with different reflectivity

The second measurement shows the approach of an object with a reflectivity 10 %. The red curve shows the distance starting at 300 cm and stops at 20 cm (Fig. 13).

It has to be mentioned that the Halios approach delivers always two independent values: the distance and the reflectivity of an object. Out of this data the reflectivity grade of the object can be calculated which might be helpful to support the identification of objects.

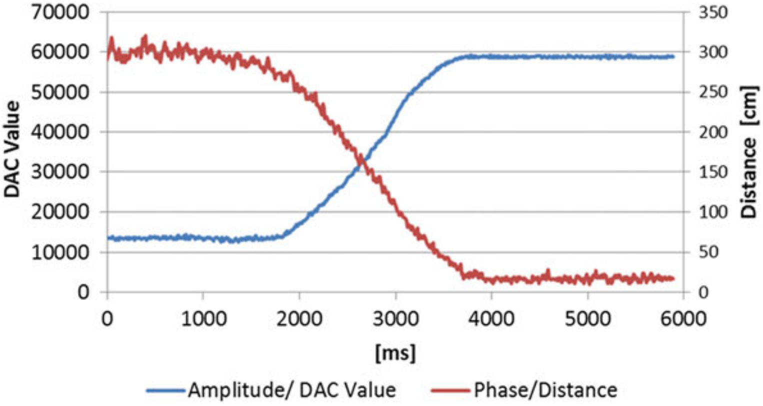

Fig. 13 Measurement of distance and reflectivity of objects with different reflectivity

4 Conclusion

ADAS have to work reliable in any condition. As a result, it is fundamental to select reliable sensors. When assessing different sensing technologies optical sensors offer a cost optimized solution, which is reliably working under harsh environments and are highly scalable compared to other sensing technologies. Sensor fusion will become mandatory to implement more sophisticated systems. Equally important is the availability of smart sensors offering intelligent methods to adjust to changing working conditions (automatic calibration, self-adjustment, diagnosis, power-down modes, embedded EMC algorithms, interfacing, on-the-fly changes, etc.).

Infrared based time-of-flight sensors will emerge in ADAS due to reliability, scalability, and best cost-performance-ratio for more sophisticated systems using sensor fusion.

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Trends in Smart Power Technologies for Automotive Applications

C. Diazzi

Abstract Smart Power Technologies, first introduced at the end of the 80s in the industry, cover today all the range of Automotive applications from Power Train to Safety, Body Electronics and Infotainment, with important macro trends of evolution and innovation led by Energy Saving. The paper describes the evolution of "BCD Smart Power" technologies for Automotive applications, looking for combined technology platforms were digital content, high voltage and current are present in the single chip. Advanced technology nodes down to 0.11 μm microlithography are described, with Voltage capability in the range from 40 to 100 V. High Current, severe Energy dissipation, extended life time and temperature range are going to require robust solutions in terms of thermo-mechanical stress capabilities for the interconnections and the BEOL (Back End Of the Line). Concerning High Voltage usage the Hybrid/Electrical Vehicles are going to require High Voltage Gate Drivers Technologies (600 V) and specific solutions for Galvanic Isolations (6 kV).

Keywords Smart power technology · BCD technology · Microlithography · High voltage · Energy saving

Glossary

BCD	Bipolar, CMOS, DMOS
VIP	Vertical Intelligent Power
Ron × A	On Resistance of a Power Device Multiplied by its Silicon Area. It's a Figure of Merit of Efficiency of Integration of Power Devices
SPI	Serial Parallel Interface

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1 Introduction

Energy production and consumption has geopolitical and environmental consequences and is a topic of worldwide concern.

Transportation accounts for 18 % of global energy consumption, and cars count for 8 % of that.

Transportation produces about 20 % of energy-related carbon dioxide (CO_2) in-atmosphere emission. This impacts global warming due to the greenhouse effect of CO_2.

In view of the trends forecast over the next few decades, much attention is being given to reducing this impact, which is backed up by strong legislation regulating CO_2 emissions and fuel consumption.

Automotive electronics play a key role in energy saving enabling the evolution for:

- Engine control with electrical actuated injection, which is the only way to ensure precise fuel dose
- "Car electrification", going from the migration of mechanical to electrical actuation of the loads supporting driving and safety, to the innovative solutions for hybrid or full electrical devices.

2 Silicon Technologies for Automotive Applications

Silicon technologies in general apply today to a very wide spectrum of automotive applications; as reference Fig. 2 shows a summary table of Voltage Ranges and Current ranges covered for different applications by technology families: CMOS, BiCMOS, eFLASH, Power Discretes, Vertical Intelligent Power, BCD (Bipolar/CMOS/DMOS-Smart Power).

IC Smart power Technologies for Automotive are following a different roadmap compared with other applications were C-MOS based scalability is well established, belonging to the "More than Moore" roadmap [1–3].

The new requirements in terms of power and voltage are setting a specific trend, looking for a combined technology platform were digital content, energy capability, and high voltage and high current are present in a single chip (Fig. 1).

In Table 1 the automotive applications covered by smart power technologies are mapped with the main voltage classes required.

The listed voltages are the maximum operating voltages guaranteed by the technology; for example the 48 V applications are covered by the 60 V class technology.

The output working voltage range (in the past limited to 70 V) is now extended to 600 V and is due to a new age that is opening for the engine conception.

In the following of the paper focus will be put on BCD Smart Power Technologies.

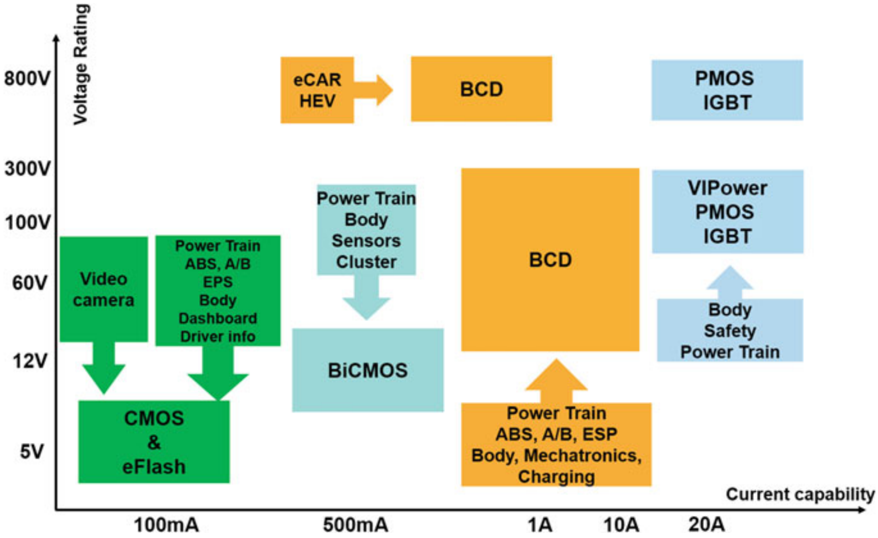


Fig. 1 Silicon technologies versus automotive applications

Table 1 Automotive applications voltage rating

600 V	Hybrid electrical vehicle
300 V	Diesel direct injection (Piezo 250 V) Diesel direct injection (Magnetic 150 V)
100 V	Gasoline direct injection
60 V	Gasoline injector drivers Solenoid drivers Alternator regulator High power loads (heaters, conditioning, power steering, pumps) HEV battery management
40 V	ABS, ESP, Airbag, Motor drivers Linear regulators, DC/DC converters Relays drivers, lamps drivers LED drivers

3 BCD-Smart Power Technologies for Automotive Applications

3.1 BCD (Bipolar-CMOS-DMOS) Technologies

BCD technologies are characterized by the fact that, with respect to other technologies, they can offer a wide possibility of integration capability. They allow to cover more and more single chip solutions and the integration of Digital CMOS, Analog and Power Stages in very flexible configurations (Low Side Power, High Side Power, Half/Full Bridge, …).

Today Smart Power technologies are approaching the 100 nm litho barrier due to the increasing complexity required for integration at system level; there are anyway important driving forces, other than microlithography, which characterizes the developments.

The demand for higher voltages, currents and robust behavior in the system is opening the doors to more sophisticated isolation approaches. Dielectric Trench Isolation and Full Dielectric Isolation (SOI) are going to replace the standard Junction Isolation.

SOI technologies show benefits in terms of die size in the implementation of High Voltage Power devices (Voltage rating > 100 V) [4, 5].

The trade-off is not pure technical, but cost is an important parameter that must be taken in account; Dielectric isolated technologies add cost but can benefit of die size reduction and more robust behaviors in driving inductive loads.

3.2 BCD9s (110 nm) Smart Power Technology for Automotive Applications

BCD9s (0.11 μm) is a proprietary STMicroelectronics technology specially conceived for Automotive applications.

The technology is modular and allows the best trade-off between performances/application needs/cost; masks can be added according to the application and the required voltage ratings.

In the basic process option the technology features a voltage rating up to 40 V, with two gate oxides

- 12 nm Gate Oxide for 5 V Analog CMOS and for the Gates of the High Voltage Power Components which are optimized for a very low On-Resistance
- 3.5 nm Gate Oxide for 1.8 V Digital CMOS with ~120 KGates/mm^2 gate density, which is suitable for digital intensive applications

The voltage rating of the High Voltage and Power components can be increased up to 60, 80 and 100 V adding dedicated doped wells.

The technology is conceived with a deep N+ Buried layer for robust and safe driving of inductive loads.

The metallization scheme implements a full copper solution that includes 4 metal levels, 3 thin damascene copper metals for signal routing and 1 thick copper metal for Power routing.

The technology architecture allows, for all the high Voltage classes available, Low Side and High Side configuration; hence it is possible to implement in a single chip Half Bridges and Full Bridges topology.

On top of the achievable complexity in terms of functions integration, the best in class Ron × A for all High Voltage Power ratings is also offered.

Table 2 BCD9s (110 nm) main technology features

Base options	CMOS	1.8 V CMOS Digital density $\sim$120 KGates/mm^2
	Low voltage	5 V NPN, 5 V zener 5 V poly capacitor Polysilicon resistors (600 Ω/Square) FTP EEPROM
	Medium voltage	18 V isolated PNP 18 V Nch, 27 V Nch. 18 V Pch, 25 V Pch 30 V Metal/Metal capacitor
	High voltage	40 V NDMOS; 40 V Diode 32 V Pch, 48 V Pch
	Metal levels	3 Thin Cu metal layers: M1 Pitch 0.3 µm, M2/M3 Pitch 0.38 µm 1 Thick Cu power metal: Thickness 10 µm, Pitch 30 µm
High voltage options		60 V NDMOS, 80 V NDMOS, 100 V NDMOS 60 V Pch
Ron × Area		40 V: 24 mΩ × mm^2
		60 V: 65 mΩ × mm^2
		80 V: 100 mΩ × mm^2
		100 V: 160 mΩ × mm^2

Table 2 summarizes the main technology options.

A lower cost version of the technology is called BCD9sL.

It is conceived for less demanding applications in terms of digital content and power features, with a single gate oxide (7 nm) for the 3.3 V Analog and Digital CMOS and for the gate Oxide of the Power components, it provides a trade-off between performances and costs.

The Digital CMOS for BCD9sL allows a gate density of $\sim$70 Kgates/mm^2.

4 Fuel Injector Driver Application and Evolution

Electrical actuated injection is the only way to ensure precise fuel dose actuation.

A typical system includes a number of sensors, injectors, valves, heaters and relays that are controlled by an Electronic Control Unit (ECU).

Thanks to the evolution over the years of BCD-Smart Power Technology it was possible to offer more and more functions in a single chip, improving engine efficiency with state of the art silicon solutions.

The first example dates back 20 years ago with the introduction of the first fully integrated Injector Driver IC for single point injection in the industry realized with the first generation BCD1 Technology (4 µm).

This anticipated the application need for precise control of the injected fuel and for advanced diagnostics.

In the latest development, BCD9s technology described in previous chapter allowed the integration of the analog, power and driver stages, the power supply and three programmable µ Cores.

This flexible structure enables fast and accurate parallel task management, thereby saving computational resources in the main microcontroller, allowing a perfect fit for a EURO6 gasoline direct injection system.

Another example of integration capability of BCD technology is the latest generation of U-Chip assembled in a HI QUAD power package which, along with a microcontroller, embeds all the

Functionalities needed to build Engine Management ECU targeting four-cylinder applications.

It integrates the following functions:

- power management section to supply microcontrollers and sensors
  - 40–5 V @ 0.4 A, 2 × 5 V @ 0.1 A
  - 40–3.3 V @ 0.1 A
- 17-channel power driver for injector, valves, heaters and relays
  - 2.4 Ω, 0.6 A, 40 V Main Relay Driver
  - 0.72 Ω, 1.25 A, 60 V, 4 mJ/200Mcycles, Injector drivers
  - 0.47 Ω, 3 A, 40 V, O_2 Heaters
- 8 flexible power drivers that can be configured as stepper motor drivers or high/low side drivers
  - 1.5 Ohm, 1 A, 40 V
- 3 channel Power MOS pre-drivers
  - 5 V, 20 mA, 50 V versus GND
- 4 channel IGBT pre-drivers for ignition
  - 14 Ohm, 30 mA, 20 V

Due to increasing demand for speed and security in chip-to-chip communication the device is equipped with SPI and Micro Second Channel protocol interface and with a safety Watchdog supervisor.

Figure 2 shows the evolution of BCD-Smart Power Fuel Injector Drivers from STMicroelectronics, form first generation BCD1 (4 µm lithography) to the more advanced one BCD9s (0.11 µm lithography).

5 BCD-Smart Power Technologies for HEV Application

Figure 3 shows a functional overview of the Supply System for an Electrical/Hybrid vehicle.

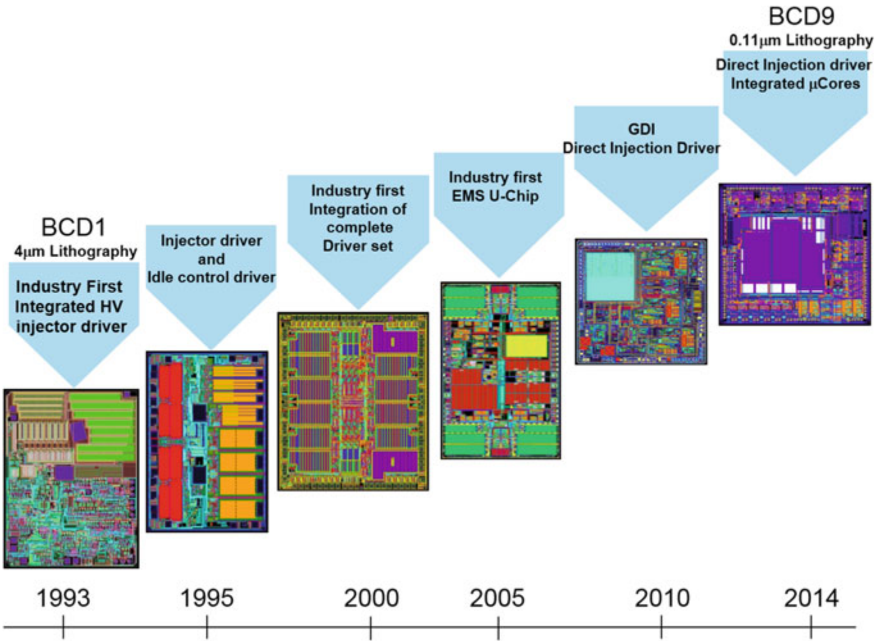
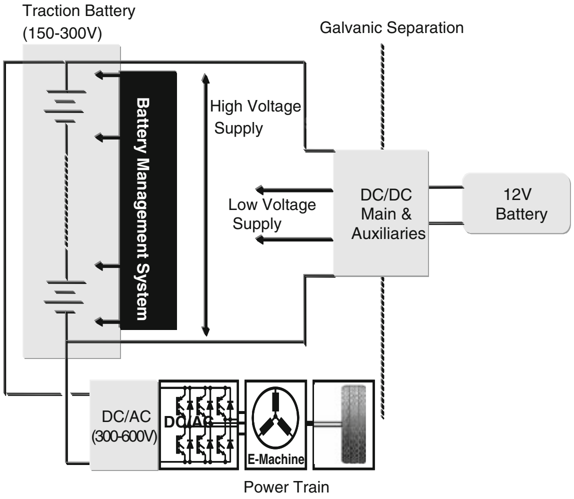


Fig. 2 Fuel injector driver application evolution in ST BCD technologies

Fig. 3 Functional overview of supply system for electrical/hybrid vehicle



The standard electrical drive train system includes a high voltage battery pack (150–300 V), the main inverter for traction (400–600 V), and the Buck and Boost DC/DC Converters for auxiliary loads and for the inverter supply.

Galvanic isolation is required between battery side and the HV drive train system.

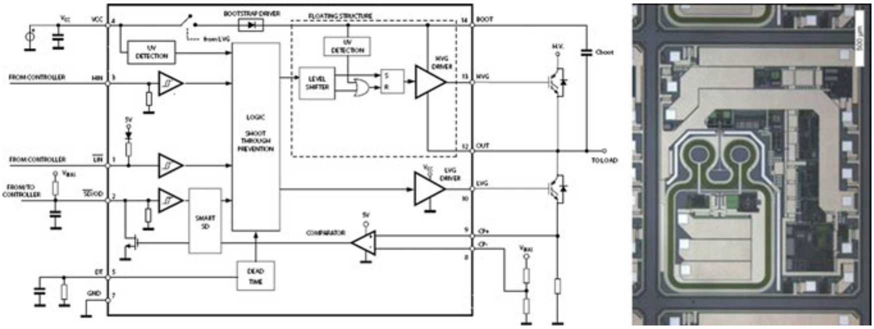


Fig. 4 Chip photograph of BCD 600 V HV technology and application schematic

The High Voltage DC/DC Converter must be able to provide bidirectional power flow and work at very high frequency and efficiency with an output power in the range of a few KW.

New requirements are coming as far as battery management and control.

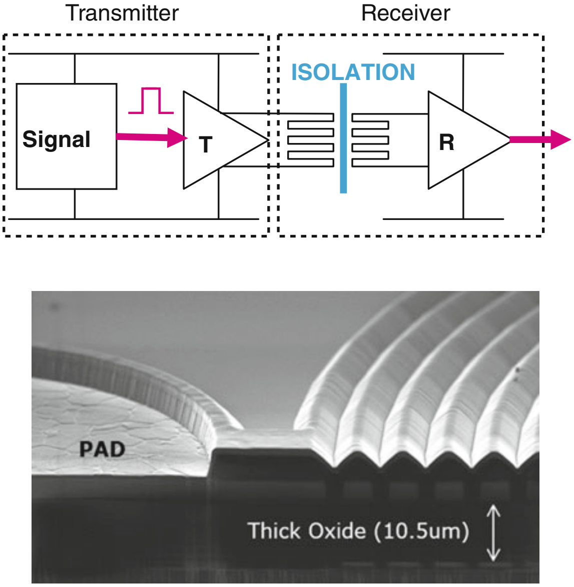
It must be provided cell voltage monitoring and charge balance with the need of sensing very high current, possibly with as low losses as possible.

In this field new opportunities are there for BCD technologies as High Voltage Gate Drivers for High Current discrete Power MOS or IGBTs.

In Fig. 4 it is shown a High Voltage Gate Driver implemented with 600 V BCD6s Offline Technology and an application example.

Figure 5 shows another High Voltage Driving application were galvanic isolation is requested.

Fig. 5 High voltage galvanic isolation. Integrated transformer



A transformer is integrated on a BCD Driver to allow >6 kV isolation, the solution is obtained interposing between two metal layers (primary and secondary) a thick oxide (>10 µm) able to guarantee the isolation voltage.

6 High Current, High Power, High Energy Capability

State of the art Smart Power technologies, thanks to the progresses in terms of microlithography and power devices improved architectures, are able to provide lower and lower Ron × Area figure of merits in terms of power integration capability.

Even if a limit can be put as far as maximum current capability for an integrated power device in the range of 10–15 A (for higher currents power discrete or VIPower technologies [6] are more suitable), the power density to be managed is continuously increasing.

These limits, together with the tough requirements of 15 years lifetime, 10000 h in Power On and, moreover, power pulse cycling (see Table 3) that are causing severe thermo-mechanical stresses on Inter Dielectric Layers [7], are just a few examples of the main challenges to be addressed when designing Smart Power technologies and products.

To overcome these failure mechanisms, new metallization solutions have been proposed and multi-layer metallization [8] and or thick copper metal layers are today used. Figures 6 and 7 show two different solutions for thick Cu metallization on Smart Power technologies.

The thick copper selective electroplated technology allows higher thickness and is used for power metal as re-distribution layer.

The thick Cu-damascene technology is more VLSI oriented; it allows lower thickness but thanks to finer pitch can also be used for signal routing.

Figure 8 shows the improvements obtained in silicon areas from previous generation BCD generations both in terms of Ron limitation and Energy pulsing capabilities.

Optimized solutions to manage high power and energy dissipation need to take into account package technology.

Silicon technology and package technology need to be developed in a concurrent way to get the best benefits at application level.

Table 3 Energy pulses as required in engine management systems

Mode	Energy mJ	# Pulses
Operative	15	50 M
Jump start	50	10 k
Load dump	100	5

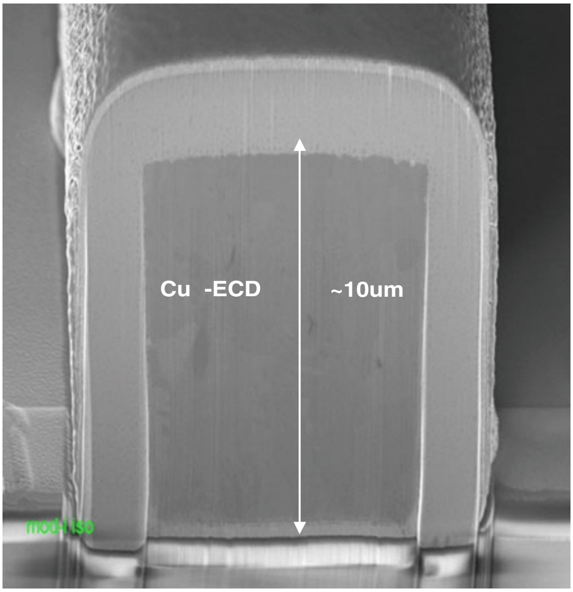


Fig. 6 Thick copper obtained by selective electroplating

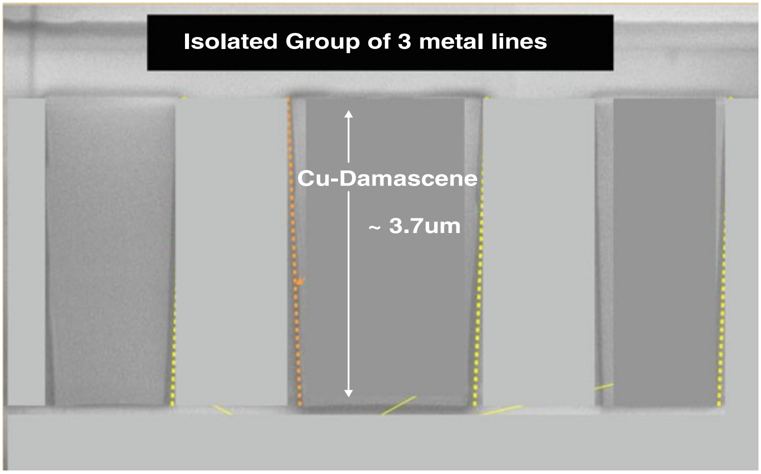
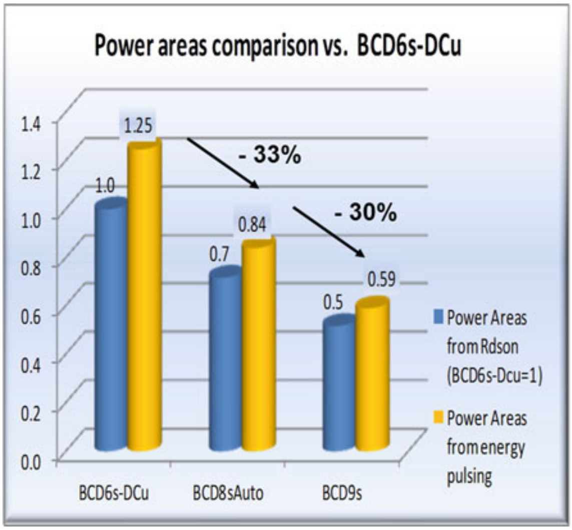


Fig. 7 Thick copper damascene metal strips

New packages with high pin count, high power dissipation capability, small outline and low cost need to be conceived and developed; front end silicon and back end package technology compatibility is a major challenge that will become more and more important in the future.

Fig. 8 Improvements in Silicon Area for ron and energy pulsing capabilities



7 Conclusions

Today BCD Smart Power Technologies are covering a wide spectrum of automotive applications, extending their utilization to the high voltage requirements driven by new concepts in the Engine and auxiliaries evolution.

Microlithography is a driving force for added complexity in the digital control sections, and still is able to provide benefits in the Ron × Area figure of merit of the power sections.

The “More than Moore” approach will bring even more differentiation and new solutions to address the needs of high current, high energy and power dissipation, superior quality and lower costs.

Acknowledgments The author wishes to thank his colleagues Paola Galbiati, Giampietro Maggioni and Vanni Poletto for their contribution to this paper.

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Photonic Technologies for the Automotive Industry

Carlos Lee

Abstract European Photonics Industry Consortium (EPIC) in cooperation with TEMATYS has conducted a study on utilisation of photonics in automotive applications. This paper describes in brief the main conclusions of this study related in particular to automotive driving, ADAS, interior electronics and the green car.

1 Introduction

From being a very traditional industry just a few years ago, the automotive sector has become one of the main industries that drive innovation, both in R&D investments and in their practical application. The Boston Consulting Group annually report the ranking of the most innovative industries. Ten years ago there were only 3 car makers in the top 50 of the most innovative companies (Toyota, Ford and BMW), by 2013 the automotive industry was in first place, with 30 % of the ranked companies in the Top 50, before many high-tech and blue chip companies. Innovation in power, through hybrid and electric engines, was and still is the most funded domain. But connectivity of vehicles, advanced driver assistance systems and lightweight materials are gaining momentum. As described in the EPIC report, photonics is a perfect enabler for these domains through advanced sensors and lighting, new displays and new manufacturing processes. In the next few years, industrial photonics companies will benefit from the 8 % annual growth of investment in automotive subcontractors and component suppliers (Tables 1, 2, 3 and 4).

There is no doubt that photonics is revolutionizing the world and will have an influence similar to the semiconductor industry. Photonics includes all technologies

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Table 1 Technologies for ADAS

	ADAS				
	Imaging and sensing inside	Imaging and sensing outside	Lighting	Communication	Displays
Safety	Cameras for somnolence and driver drowsiness monitoring Thermopiles for detection of passengers presence	Backup Camera LIDAR and cameras for Adaptive Cruise Control and collision avoidance Lane departure warning system Active and passive IR systems for night vision and pedestrian protection Blind Spot detection (mirrors, Fresnel lens, …) Photodiodes, IR sources for rain detection, luminosity monitoring, …	Adaptive headlamps	Camera for traffic sign recognition and cameras/scanners for Intelligent Speed Adaptation VLC for V2V communication about traffic and safety issues	Head-up displays (HUD), holography, projectors, combination with augmented reality

that use light, create light, detect light, or modify light. Photonics is having a profound impact on a very diverse range of applications such as agriculture, energy, entertainment, lifescience, transport. Photonics is one of the six key enabling technologies recognized by the European Commission, and is well placed to address our most pressing societal challenges. EPIC invites automotive manufacturers and component suppliers to engage with the photonics value chain. The photonics industry is very strong in Europe with more than 5000 registered companies. But, as an emerging industry, most of these companies are small and young. Indeed, 86 % have less than a hundred employees, yet these companies are extremely innovative and therefore a rich source of technology and innovation.

Table 2 Technologies for the exterior of the car

	Exterior			
	Imaging	Sensing	Lighting	Communication
Safety			Halogen lamps, HID, LEDs, Lasers, OLEDs for head lights and signal lights	
Comfort	Cameras for gesture recognition and proximity detection	Spectroscopy for outdoor air quality monitoring IR active systems for gesture recognition		Optical communication (Photodiodes, VLC) for car to X communication
Entertainment			Diffractive optics for branding	

Table 3 Technologies for the interior of the car

	Interior of the cabin				
	Imaging	Sensing	Lighting	Communication	Displays
Comfort	Cameras for rear passengers observation	Spectroscopy for air quality monitoring Cameras, IR sources and photodiodes for gesture recognition	Halogen lamps, Neon lamps, LEDs, OLEDs for interior lighting (footwell, dome lighting…) Optical fiber, Diffractive optics		HUD and HMD to provide basic information to the driver (GPS, speed, fuel consumption, …)
Entertainment				MOST (Media Oriented Systems Transport) for communication between media in the car (audio, video, …) Plastic Optical Fiber	LCD, electrochromic displays, … for passengers

Table 4 Technologies for green cars and manufacturing

	Green car and processing			
	Imaging	Sensing	Energy	Processing
Traction			Solar cells to supply the car (replacement of batteries)	
Comfort		Spectroscopy for exhaust gas sensing, oil quality monitoring	Transparent Solar cells to supply low consumption functionalities (air conditioning, …)	
Manufacturing				Lasers for cutting, welding Micromachining (diesel nozzles)

If you are looking for a technology supplier, a partner for a collaborative research project, and wish to engage with the photonics industry, you are invited to contact EPIC and we will be pleased to connect you with the members of the association.

Part VIII
Human Factors in Modern Cars

The Smart Connected Seat to Enable Real Life on Board Vehicle Proposition-Renault NEXT TWO (*) Connected Seat Show Case

I. Alvarez, G. Millet and F. Mathis

Abstract Today's Automotive industry is vastly aligned on the premises that current society's evolution on ways to communicate, manage data, and interact with intelligent objects is going to define the future vehicle—life on board-services and the corresponding interior's performance value. In fact, synchronized with the technological evolution, the way how population establishes relations between among intelligent objects (nomadic devices and home appliance, vehicle, etc.) is changing extremely fast towards extensive "self" concept and setting basis for new era of customer satisfaction requirements. Aging and Youngers car users of today are getting used, in the aside connected world of the car, to customized propositions, that allow multitasking, that provides them an Eco systemic functionality always available, symbiotic and interactive, a life companion (quantified self) that cares about. The Seat as part of this new Car interior is an essential enabler of such revolution as provides the unique opportunity to be one the closest vehicle part to the occupant and the first one in body contact surface, providing closed loop actions and information needed or supporting the-Life on Board-Services.

Keywords Connectedness · Autonomous driving · Life on board services

Glossary

ECU	Electronic Control Unit
TCU	Telematics Control Unit
FIT™	Faurecia SMART FIT family

(*) Renault®

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1 Introduction: Faurecia's Smart Connected Seat Show Case—Renault NEXT TWO (*)—Seat Electronics

This seat was developed in association with Renault, and features electric controls that allow its settings to be adapted to different drivers. This smart seat uses a database stored on the Cloud to determine the ideal settings as a function of the driver's build. A Health and Wellbeing application controls the smart seat which features a 'relax' mode, along with a range of multi-sensorial ambiences (lighting, audio, scent) that also help occupants to wind down and enjoy their journey safely, while the vehicle looks after the driving itself.

In this paper, Faurecia will present the Seat Electronics functions in the Renault AD car NEXT TWO (*).

2 The System Concept and Architecture

When we think in the Smart connected seat architecture and functionality of NEXT TWO, we need to do it a bit differently from current approaches in the market. This seat has as mission provide a fluent connection and integration of actions between the occupant and the car intelligence in order to provide proper life on board functions on-autonomous driving mode-while keeping safe transitions of control between the occupant and the car. This working model is totally different of today's power seat on the market where adjustments and comfort are based on open loops control systems where the occupant is closing the loop of the transfer function (adjustment, massage, climate comfort, etc.). The mode the seat electronics systems should behave for this new autonomous driving mode, are automatically closed loop. With functions where we find two levels of hierarchy among control laws: the interaction occupant and seat, close loop level 1, and the seat with the car close loop level 2. Being the third one reserved for manual actions.

2.1 *First Group of Functions*

They system was conceived with a group of functions covering first step of intelligent autonomous car:

(a) Automatic drive from Car Park to office front door (ready to go)
(b) Adjustment to occupant morphology
(c) Advanced Communication
    (i) Car ↔ Environment
    (ii) Car ↔ Occupant
    (iii) Occupant ↔ Occupant

(d) Automatic Driving with driver onboard
(e) Non driving position proposed to occupant
    (i) at office mode (Video Conference)
    (ii) Relax mode
(f) "Conciergerie"
    (i) Seat final adjustment when opening the door

The platform used was Electric Vehicle (Zoé).

To execute such functionality as first step of full automation, the system was split in 3 main control loops level, resulting on a split of 3 main system parts as we do for any controlled plant in automation:

(1) **Inputs/outputs** (getting and providing information and diagnostics on the controlled environment car/seat/occupant)
(2) **Control** (closing the loop and providing stable transfer function)
(3) **Controlled Plant** (action systems, actuators enabling life on board functionality from adjustments to comfort) (Fig. 1).

Inputs/outputs:

The system presents 3 main input interfaces:

1. Vehicle EE architecture and HMI
2. Manual commands
3. Server commands (nomadic device)

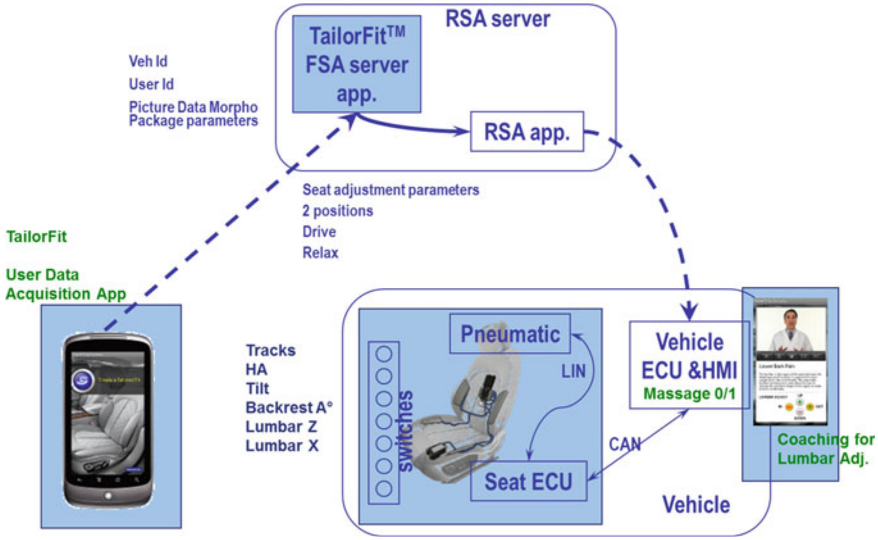


Fig. 1 Data flow system architecture

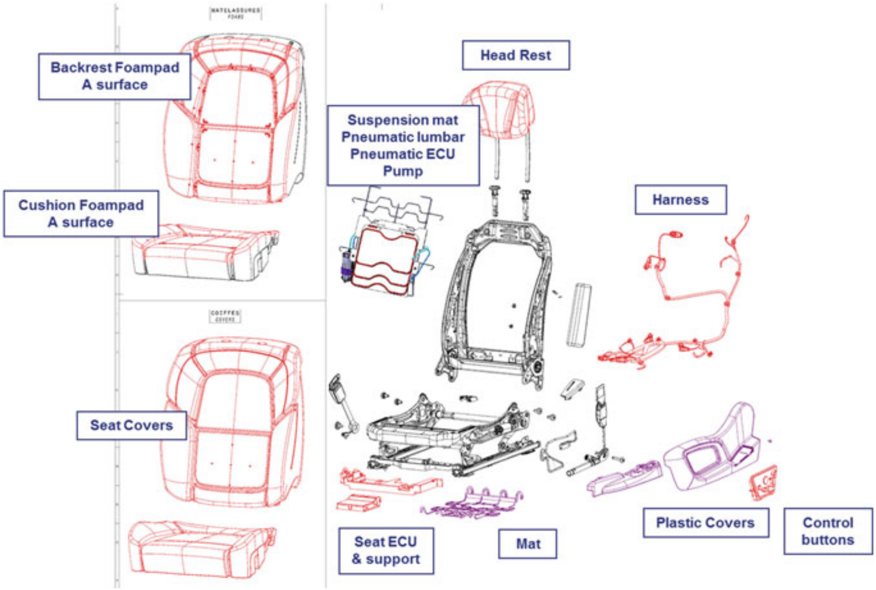


Fig. 2 Seat system components

Controls:

The system presents 3 main control loops with different degrees of autonomy:

1. Control loop P1: Nomadic device/Server/Vehicle/Seat.
2. Control loop P2: Vehicle/Seat.
3. Control loop P3: Occupant/Seat (Sensors and Manual commands).

Controlled Plant (actions):

The main actions of the seat are performed by 2 main actuation systems:

1. Power adjustments (motors/actuators)—Tracks/HA/Tilt/Backrest A°
2. Comfort adjustments (pneumatics)—Pneumatic Lumbar 4 ways with Massage—(Fig. 2).

3 The Faurecia's FIT™ Intelligence, Seat and Pneumatics ECUs FIT™ Ready

The Smart connected functionality of the seat cannot be seen as a set of components but as a system interdependent.

For this system there are 3 main contributors for the functional performance 1 being SW cloud based 2 others based on embedded HW/SW:

(a) Faurecia **FIT™ algorithm**—Computing inputs/outputs and controlling the system
(b) Seat ECU **FIT™ ready**—Controlling actuation of postural adjustments
(c) Pneumatics ECU **FIT™ready**—Controlling actuation of comfort adjustments.

3.1 Faurecia FIT™ Algorithm Along the Seat Sequence

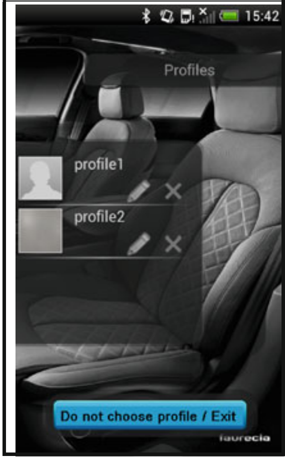
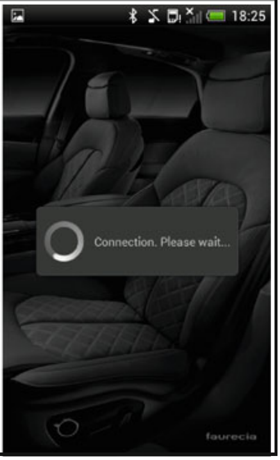
As presented before the system algorithm is split between the 3 main host platforms, the Seat ECU, The cloud server and the Pneumatic ECU.

Below the picture of one of the autonomous driving sequences we could find in the car seat. It is about 5 steps that include vehicle call, reception and automatic settings, up to delegation position.

Step 0: SmartFit™
Within this first step the user define its driver profile and accommodations. It is done via the Smart fit Application installed in the nomadic device and communicated with the RSA server. FAS algorithm is hosted by RSA server: Global Data Center (GDC). FAS algorithm already contains all vehicle characteristics. FAS algorithm computes seat settings and provide Setting Packet to RSA server.

“Setting Packet” contains:

- Driving Position adjustment for motors on Slide, Backrest, High, Tilt, and pressure for the air cells.
- Delegated Position adjustment for motors on Slide, Backrest, High, Tilt, and pressure for the air cells.

Profile selection page	Connexion to server through the Internet
	 Connection. Please wait...

Telematics unit (TCU) and Seat ECU are mutually reporting status of seat and driving conditions, this communication is done under proprietary encryption/decryption algorithms to secure data integrity.

The logic flow for such interaction on this specific case would be:

Position A (Parking lot position)

- The TCU sends to seat ECU the command to be in position A.

Position B (Intermediate position)

- The user calls the car from his Smartphone; RSA server sends to the car through WIFI the request from user.
- The TCU sends to seat ECU the command to be in position B, FAS seat ECU adjusts the settings in function of position defined by Smartfit algorithm for power and pneumatics adjustments.

Initial Position C (Initial driving position from algorithm)

- The TCU sends to seat ECU the command to be in position C.
- FAS seat ECU adjusts the settings in function of position defined by Smartfit algorithm for:
- User can move Slide, Backrest, High, Tilt, Lumbar to find his "Own Driving Position" (Position C′).

Position D (Delegated position from algorithm)

- The user request delegated position through TCU.
- When car is ready to delegate the driving, it sends to seat ECU the command to be in delegated position.
- User can move Slide, Backrest, High, Tilt, Lumbar to find his "Own Delegated Position".

Position C" (Own driving position)

- The user requests a driving position from a delegated position.
- The TCU sends to seat ECU the command to be in driving position:
- FAS seat ECU adjusts the settings to user "Own Driving Position"

3.2 Faurecia Seat ECU FIT™ Ready

In order to manage the seat power functions and to perfume the CAN/LIN gateway between the TCU and the rest of the active FIT™ seat system the seta is equipped with a Seat ECU last generation gateway with encryption/decryption algorithm and prepared to support dynamic functionality. It is 8 W power unit compatible with FIT family (Fig. 3).

The seat ECU is mounted in the seat and has direct control of motorization of seat adjustments as long as management of the LIN slave pneumatics.

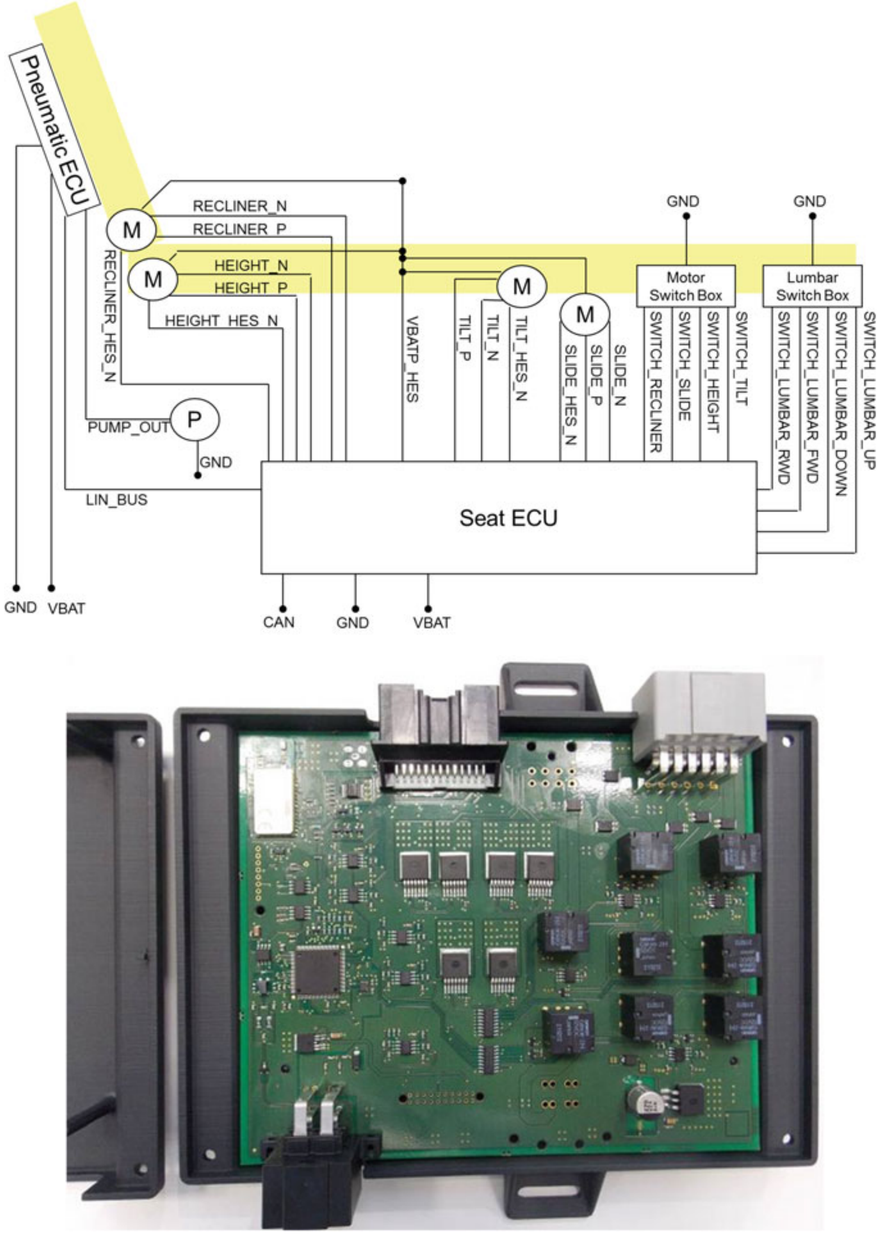


Fig. 3 Faurecia Seat ECU FIT™ ready

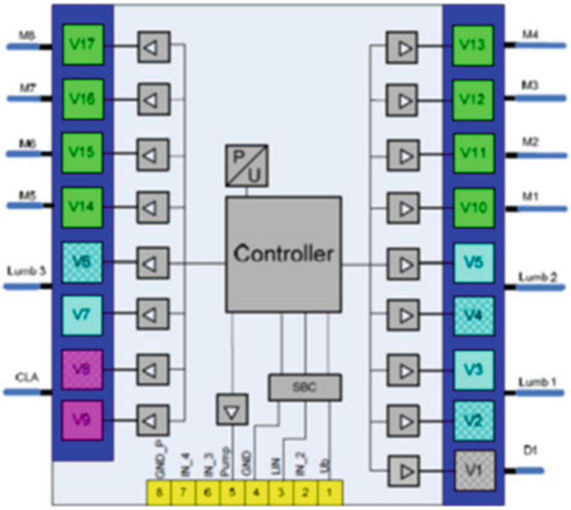


Fig. 4 Illustration of Pneumatic ECU block

3.3 *Faurecia Pneumatics ECU FIT™ Ready*

The 6 W lumbar and further optional pneumatic seat adjustments configuration it controlled by a LIN slave Pneumatic ECU. This ECU is controlling the pump and valves in order to maintain pressure targets on the bladders according to FIT™ seat system demand (Fig. 4).

4 Conclusion

In this paper has been presented the electronics architecture of the Faurecia's Seat for the RSA project NEXT TWO.

This architecture is based on connected seat, to enhance life on board for autonomous driving with distributed intelligence between the cloud, and the seat ECUs. It has been presented a show case of autonomous car driving from reset to delegation, and the interaction between the systems. The vehicle has been tested in the road with more than 5000 km driving cycle and result has been promising.

Next steps are to further develop complementary applications and functionality corresponding to the mix function proposal of the OEM and user demand.

Acknowledgements The authors acknowledge the contribution of their colleagues to this work. Especially Renault NEXT TWO seat team.

The Connected Car and Acceptance of Users High Customer Acceptance Through Functional Integration in HMI Systems

Norman Starke

Abstract Technology doesn't work very well. Car manufacturers face deepening challenges with technology as customer frustration with their multimedia systems builds. Technology issues are now the most prevalent type of problem with new vehicles.

1 The Biggest Complaint

Built-in voice recognition systems! Bluetooth connectivity is the second-most frequently reported problem, followed by wind noise and navigation problems. The problems abound even in a climate of high consumer demand for increasing levels of technology in new vehicles. Voice recognition and device connectivity are often inherent to the technology design and cannot be fixed at the dealership, creating a high level of angst among new-vehicle owners.

Consumers are frustrated because they know good technology exists. While drivers want similar technology in their cars, they want it to work, and they aren't willing to pay a lot for it, especially if they doubt the systems will work. 70 % of new-vehicle owners indicate interest in built-in voice recognition. But when given a cost of $500 for this technology, purchase intent drops to 44 %.

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2 Manufacturers Have Good Intentions, but Ultimately Their Efforts Yield Poor Results

Owners who are stuck with the glitches find themselves defaulting to unsatisfying work-around options such as knobs and controls on the steering wheel and dashboard. Despite the complaints, car companies continue to produce built-in voice recognition and connectivity systems that are not in sync with consumer expectations. Car manufacturers really need to go back to the basics and design the systems so drivers can keep their mind on the drive.

3 Car Manufacturers Consider Mobility as Their Very Own Ecosystem

Networking mobility touches the core areas of two completely different industries and associated market actors when necessary IT technology opposed to digital players set the tone. Car manufacturers who wants to look at in the future with connected cars as their originary field of activity and strive to capture the key control. But it is necessary to implement digital ideas successfully without offering unattractive ‘island solutions’.

4 Connected C@R 2014 Study

The trend has only one direction: stronger networking. The car of the future communicates continuously with its environment, with other vehicles or with the home. This development opens the car manufacturers to grow to unprecedented potentials. Particular security applications and autonomous driving are the hot topics of the coming years. In these applications there is a huge potential.

In the context of market analysis—in addition to the six functional clusters mobility management, vehicle management, entertainment, well-being, automated driving and safety—for the first time a new feature is included: Home integration. Home-integration says that the vehicle is linked to your home or your office. There by creating holistic solutions. This includes, for example, networking with the home alarm system or the heating system.

5 Crux Data Security

The sticking point for these future industry is data security. With the digital networking of cars also gateways for cyber attacks will be opened. The study identified three basic targets of networked vehicle:

Connectivity could serve as a gateway for hackers
Vehicle interfaces offer significant attack surface

Connected car could be used by botnet as a rolling computer which could remote all kind of server attacks from somewhere in the world.

The effects of a successful attack on the connected car would be fatal: From a manipulation of the brakes on the secret creation of movement profiles to remote controlled opening of the door lock—the dangers are many. Against this background, the data security is a central task in the research and development of networked automobile partners.

6 A Modern Car Communicates with Its Environment, with Other Vehicles, with the Home

This development has enormous market potential. In particular, the connected car segments safety and automated driving will provide significant growth. Mobile, networked and always-on. The social value of communication increases rapidly along with the desire of many people for permanent accessibility. This social change does not go over well at the Automobile: all-time networking in connected cars is already reality.

The driver uses the car as a communicative platform. He is used to communicate 24/7 and does not intend to miss this in the car. So it is not surprising that the market potential of networking mobility will raise between 2015 and 2020 from 31.87 to 115.20 bn € almost four times. In particular, the connected car segments safety and automated driving should assure tremendous growth.

While the market for security in 2015 is at 12.18 billion euros, the technological precursors for automated driving is at 7.49 bn €, it is expected that this potential by 2020 raises up to 47.34 respectively 35.66 bn €. Other drivers of this development are the areas of entertainment (13.18 bn euros), well-being (7.13 bn €) and vehicle management (6.67 bn €).

7 Audi Supports Apple’s CarPlay

As one of the few major car manufacturers Audi was missing on the list of Apple yet. But customers have to be patient. Audi will also support Apple’s new iOS-vehicle integration CarPlay. Many of the functions will be the future in-house installation “Multi Media Interface” (MMI). However, users still have to wait until 2015.

So far missing on Apple’s list, on which Ferrari, Mercedes-Benz, Volvo, BMW, Ford, General Motors, Honda, Hyundai, Jaguar, Land Rover, Kia, Mitsubishi, Nissan, Peugeot, Citroen, Subaru, Suzuki and Toyota were already established.

Whether VW will support CarPlay is still unclear. Google’s Android system will be intergrated in Volkswagen cars. Audi started close dialogue between the development departments of the VW-Group in Silicon Valley and Apple. What features are ultimately on the MMI platform is not yet known. Also to retrofit possibilities Audi did not give comments yet.

Audi is a founding member of Google's Open Automotive Alliance and was the first premium manufacturer there. Apple's vehicle integration for iOS 7 was officially announced in March and will be directly available in new vehicles.

8 What Technology Can Do

Starting with technology integration:

9 Conclusion

What’s requested is a simplification of parts. Not only will customers of tomorrow accept intuitive operating systems with functional surfaces, they will demand them! A perfect strategy of a future product development includes generating ideas, concept work and design adaptation. Perfect are co-operations with material and technology providers to include their advanced ideas in future products. Their focused automotive design and development know-how helps to develop prototypes with new technology applications, parts optimization as well as lightweight constructions.

Our Mission: Proof drives innovation

10 Sources

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Introducing User-in-the-Loop Quantitative Testing into Automotive HMI Development Process

Thierry Bouquier

Abstract Today, a successful automotive cockpit and HMI design is not only a beautiful and distinctive design, but also a design which reduces driver distraction and cognitive workload. Comfort and safety are at stake. Therefore, for OEMs, there is more and more value in performing quantitative measurements (reaction time, eye sight orientation, pupil diameter, etc.) of user-to-machine interactions. When done at an early development phase, these measurements are helpful in validating or rejecting HMI design concepts. ESG has started an internal project to help OEMs doing so. The project is to develop an HMI prototyping framework which includes all the facilities for bringing a potential user in front of a candidate HMI concept, and measuring how they interact with each other. The framework is able to host a wide variety of HMI prototypes, including multiple screens, innovative input methods and various actuators. After a test campaign is achieved, with several users, the framework enables statistical processing of measurement results, for later analysis (by ergonomists, for instance). ESG has finished the first phase of this project. They are ready to show a proof-of-concept demonstrator of this framework.

Keywords HMI · Prototyping · Driver distraction · Cognitive workload

Glossary

ADAS	Advanced Driver Assistance System
COTS	Commercial Off-The-Shelf
GUI	Graphical User Interface
HMI	Human-Machine Interface, or Human-Machine Interaction
IVI	In-Vehicle Infotainment
OEM	Original Equipment Manufacturer
UIL	User-In-the-Loop

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1 Introduction

For automotive OEMs, the cockpit, i.e. the area around the driver's seat, has always been a challenging one to design, not only to fit to the driver's needs but also because part of this area is shared with the front passenger. Cockpit design is strategic for user experience, user-perceived quality and brand image.

Introducing high-tech electronics in the cockpit, like fully digital instrument clusters with advanced colour animations, opens a wealth of opportunities for OEMs to propose stylish, cool and dynamic cockpit designs to their customers. However, it also creates new risks and additional customer expectations.

For instance, consumers are expecting to bring their apps from their smartphones into the vehicle and to be able to use the apps seamlessly. Due to this social trend, OEMs are being tasked with adding "Smart Phone Application" features into the cockpit, either by enhancing car-to-smartphone connectivity, or by adding an app framework to their embedded systems.

At the same time, OEMs face the increasing pressure of contributing to road safety by minimising driver distraction. Any new and smart electronic feature introduced in the cockpit might come with additional causes of distraction.

Information to the cockpit needs to be assessed on the proper and safe way to present information with minimal cognitive load.

New human interaction innovations suggest that using input from gesture, facial, eye, and voice recognition systems might help to minimize cognitive workload, because the driver would need to spend less effort on being "understood" by the vehicle. Cockpit information is also taking on new forms such as, but not limited to, lights, sounds, and vibrations, IR cameras and other sensors/actuators. These are solutions to provide the right signal at the right moment.

In this context, cockpit engineering teams need to enhance their development process and tools. On one hand, they are facing increasing challenges. On the other hand, they can benefit from innovative technologies to solve those challenges.

One key challenge is to be able to quickly build HMI prototypes, in order to validate what kind of interaction is the best way to provide information safely to the driver, giving priority to safety items, followed by other information based on OEM criteria.

This paper will expose a solution to optimise the use of such prototypes within the cockpit development process. This solution is based on objective quantitative measurements of user-to-machine interactions.

By analogy with existing techniques called Model-In-the-Loop (MIL), Software-In-the-Loop (SIL) and Hardware-In-the-Loop (HIL) testing, this solution is referred to User-In-the-Loop (UIL) testing.

2 Vision of the Final Framework

From ESG's HMI experience, cockpit design teams need more than HMI prototypes. They need a complete HMI prototyping system, or platform.

What is the difference? An **HMI prototype** attempts to be a clone, or a model, of the system which is under development. Therefore, it is usually restricted to the specific input/outputs, functionalities and technologies of the target system (Fig. 1). When these are changed, the engineering team needs to develop another prototype. Now, when ergonomics comes into play, cockpit design teams need to question their choice of input/outputs, functionalities, or technologies.

On the other hand, an **HMI prototyping platform** is a system whose purpose is to be the common base for several prototypes. It is designed to make it easy for HMI designers to develop prototypes from the same technical framework, and to compare these prototypes with one another. The platform is adaptable and configurable, both in hardware and software, in order to make it easy for system designers to see what happens when they add or remove a given input/output, functionality or technology (Fig. 2).

In a way, an HMI prototyping platform can be seen as a tool in support of the system development process.

To achieve adaptability and configurability, reuse and modular approach are mandatory for this kind of support.

This paper presents an improvement which consists in **adding user observation capability** to the platform. Today, it is possible to make quantitative measurements of the way a human behaves in front of a machine. The required technologies have reached sufficient maturity:

- voice recognition,
- gesture recognition,
- eye tracking,
- face recognition.

These measurements will enable OEMs to better understand human-machine interactions. It will enable them to quantify HMI improvements (quicker user reaction time, less cognitive workload, best prioritization, etc.). In the future, it

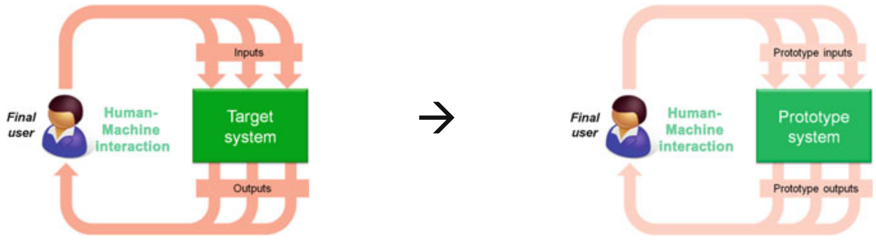


Fig. 1 Notion of simple HMI prototype

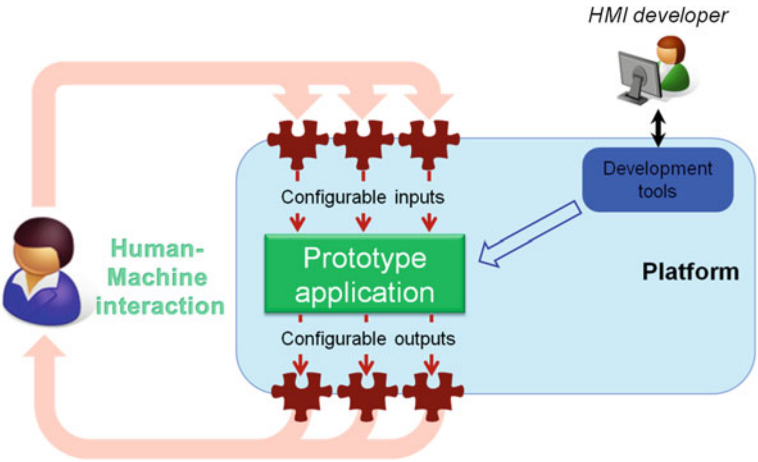


Fig. 2 Notion of HMI prototyping platform

might event enable them to specify the "quality" of an HMI in terms of quantified requirements.

For example:

> An OEM has asked a Tier 1 to implement a first version of the HMI. When performing user experience testing, the platform measures that a typical driver takes 3 s to understand one pop-up message before responding correctly. This creates safety issues.
>
> This means that the message generates too much cognitive workload. To improve the HMI, the OEM writes a requirement asking that the typical driver reaction time shall be below 1 s.

For observing human-machine interactions, one might use external instruments. ESG's concept is to **integrate those instruments into the prototyping platform** (Fig. 3).

This way, quantitative measurement will become fully integrated into the HMI development process. It will belong to the standard way of working, instead of being confined to one-shot ergonomics studies. Potentially, this will shorten feed-back loops on HMI design, which is a proven way of reaching time-to-market with the proper level of quality and cost effectiveness (Fig. 4).

Each step of the cycle comes with its own set of challenges. Especially, this paper will **not** focus on:

- [in Step 3] the different sensor and algorithmic technologies which might be used to observe and measure the user (e.g. eye tracking);
- [Step 4] how to perform statistical analysis of measurement results and to draw conclusions on the strengths and weaknesses of a candidate HMI design (e.g. how to detect excessive cognitive workload by analysing user reaction time);
- [Step 5] how to enhance an HMI concept once analysis results are known (e.g. how to simplify menus to reduce cognitive workload).

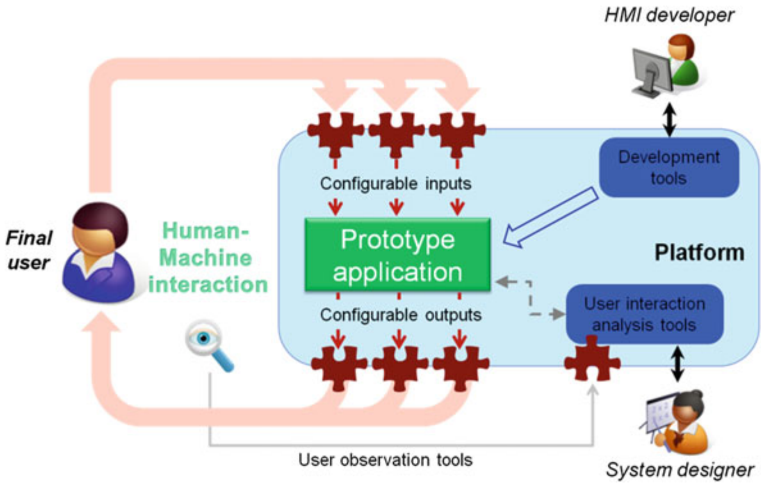
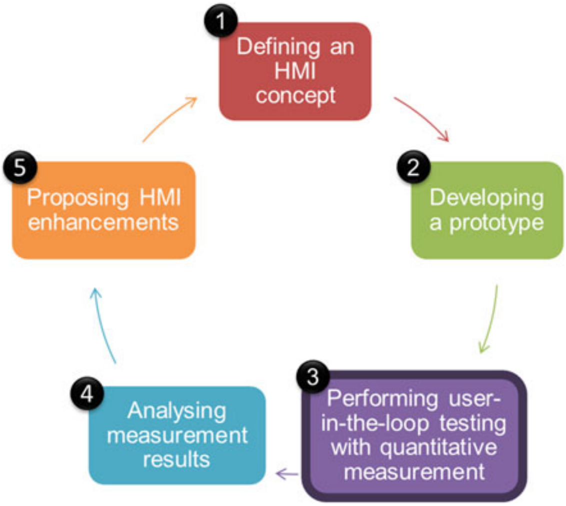


Fig. 3 Notion of HMI prototyping platform with user observation capability

Fig. 4 HMI development loop based on quantitative measurements of user observation



This is because those steps require specific skill sets, respectively:

- sensor technology and signal processing;
- human factors engineering;
- ergonomics.

Instead, the paper will focus on the **core technical solution** required for Step 3: how to add user observation capability as a central feature of an HMI prototyping platform.

3 Core Technical Solution

3.1 Technical Specifications

To add user observation capability, the platform must include some kind of **unified measurement backbone**. This backbone is connected to all user observation sensors. Typically, it is a piece of software running on a central computer.

The backbone is in charge of:

- enabling and disabling capture;
- collecting all captured data;
- making sure all captured data are properly time-stamped with a common time base;
- if required, performing on-the-fly signal processing of captured data;
- recording captured data for later analysis.

It might also be in charge of replaying data records. Ideally, it is able to perform real-time replay, to facilitate analysis.

Its main source of data comes from human observation sensors, such as eye trackers, accelerometers, or sensors for pupil diameter, body temperature, blood pressure, etc. Those sensors are usually independent from the HMI prototype.

However, the backbone is also able to capture events which are directly related to the prototype:

- user input events, such as button push, switch change, finger touch on a touchscreen, etc.;
- user output events, such as pop-up window display, sound notification, change in screen luminosity, etc.

This makes it possible to detect correlations between human behaviour and machine behaviour—for instance, user reaction time after a notification.

Optionally, the backbone is also able to capture internal events within the prototype (e.g. a change in operational state). Although these events are not seen or experienced by the user, recording them might help engineers understand specific test records.

Developing this measurement backbone is a technical challenge because of the wide variety of data sources:

- Some are software events and others are hardware events.
- Captured data come in many forms: binary states, real numbers, character strings, images, digitized audio, etc.
- Some data acquisitions are periodic, with different acquisition rates, and other acquisitions are event-triggered.
- Connections between the backbone and the data sources are diverse:
  - pure software connection (inter-process communication),
  - direct capture,

  - communication link with standard or non-standard protocol,
  - etc.

The more diversity the backbone is able to handle, the more freedom HMI designers have for selecting the appropriate solutions and performing trial-and-errors.

Especially:

- Whenever a new version of the prototype is submitted to testing, it shall be possible to adapt the backbone to any modifications in user input events or user output events, compared with the previous version.
- The same prototype might be submitted to several test campaigns focussing on different aspects of user interaction (e.g. "user learning curve", "autonomous driving", "ADAS" or "driver distraction"). Depending on the campaign, a different set of human sensors might be used. It shall be possible to configure the backbone for each campaign.

This is why, for their internal project, ESG searched for a **generic, adaptable and configurable solution** for the backbone.

3.2 Enabling Technology

To implement the backbone, ESG has found a commercial solution that fits to the technical requirements.

This solution is a development tool which is mainly for system engineers looking for a way to perform fast prototyping of advanced multisensor functions, such as ADAS or autonomous driving functions.

However, in their internal project, ESG did not use the tool for HMI prototyping, but for implementing the user observation measurement backbone.

The tool concept relies on **block diagrams** (see Fig. 5). A block diagram is an executable model of the system which is being prototyped. The system is broken down into executable blocks and into data links between blocks. A block represents either an input data source, an output data sink, or a data transformation/processing algorithm.

This commercial solution is actually a coherent set of several items:

- the Studio, a GUI software tool running on a development PC, for creating block diagrams in a user-friendly graphical way;
- the Engine, a software library for running block diagrams on a given target;
- the Component Library, a set of standard and usual blocks;
- the SDK, for creating customized blocks by coding them in C++.

For running the Studio or the Engine, the target must be a PC running on Windows or Linux.

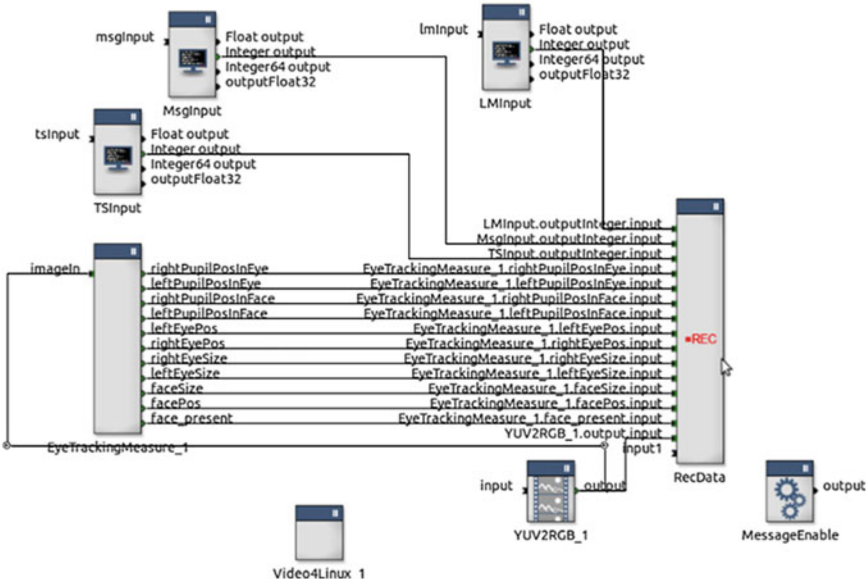


Fig. 5 Example of diagram used in the project—recording diagram

Compared with similar graphical programming solutions, the one that ESG has selected makes it possible for each block to work at different timing patterns, whether periodic, with different periods, or event-triggered. The runtime Engine is in charge of timestamping every piece of data flowing in or out of a block, making sure that all time stamps are based on the same time base.

The Component Library includes two standard blocks which are of special interest for the project.

The Recorder: on a diagram, this block only has data inputs. It gathers data coming from several flows. Its role is to copy these data, with their timestamp, into a record database. Recorded data can have different data types (binary, real numbers, CAN frames, video, audio, etc.) and follow different timing patterns, but they are all grouped into a single database.

The Player works symmetrically: on a diagram, this block only has outputs. It extracts data from a record database (previously created by the Recorder) and replays them into the diagram.

This way, a system engineer willing to prototype a system can combine two diagrams.

The main diagram is the model of the system being prototyped, with its sensors, actuators and algorithms. It runs on the prototype target. It includes the Recorder block, in order to get traces of experiments.

The replay diagram runs on a development PC. It includes the Player block. Its role is to replay traces which had been recorded by the main diagram. The Studio tool has the ability to run this diagram **in real time**, complying with the timestamps stored in the record database.

3.3 Implementing the Backbone

For the project, the chosen commercial solution meets all requirements because it makes it possible to capture all user observation data, coming from a wide variety of sources and timing patterns, and to record them, with their timestamp, into a single trace. It also includes a feature for replaying the traces for analysis (Fig. 6).

Therefore, the backbone is mainly made of two diagrams.

The Recording diagram runs during experiments, while users are interacting with the HMI prototype. Its role is to capture a set of data which have been previously identified as valuable. Those data can come from:

- user input events going into the HMI prototype, or
- user output events coming from the HMI prototype, or
- internal events from within the HMI prototype, or
- human observation sensors.

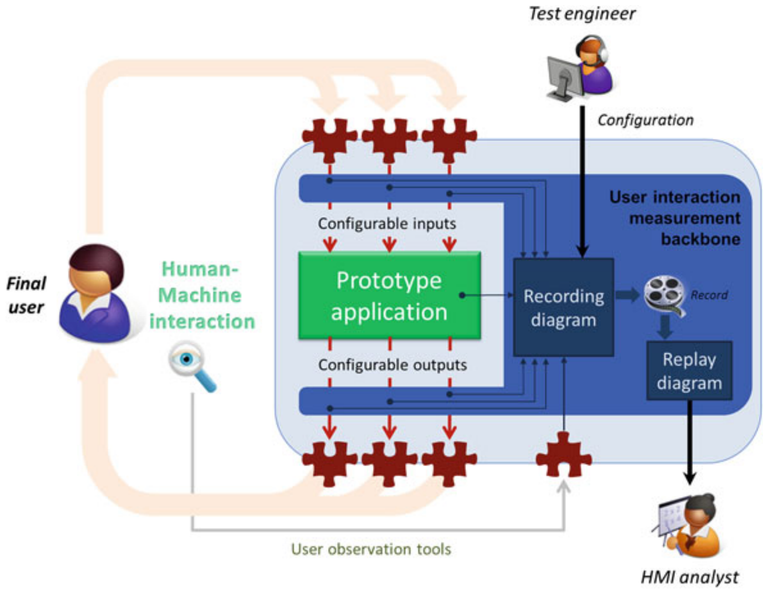


Fig. 6 Implementing the user interaction measurement backbone with the selected solution

On the diagram, all these data flows are connected to a Recorder block.

Before starting the experiment, the engineer in charge of UIL testing configures the diagram, in order to select which data will be captured. Whenever a new version of the HMI prototype is being submitted for testing, the test engineer has the ability to change this configuration, for example to capture a new user input event. In addition, whenever the prototype is submitted to a different test campaign with different human observation sensors, the test engineer has this same ability to change the configuration of the recording diagram.

Figure 5 is an example of Recording diagram.

The Replay diagram runs after experiments are done. It includes a Player block. Its role is to replay traces which had been recorded by the Recording diagram. An HMI analyst uses this diagram to characterize how users interacted with the HMI prototype during the experiments, and to draw conclusions out of these observations (Fig. 7).

If necessary, the Recording diagram can include filtering blocks or pre-processing blocks, in order to reduce the amount and to increase the relevance of recorded data.

Similarly, the Replay diagram can include complex post-processing blocks, in order to show interesting data to the HMI analyst.

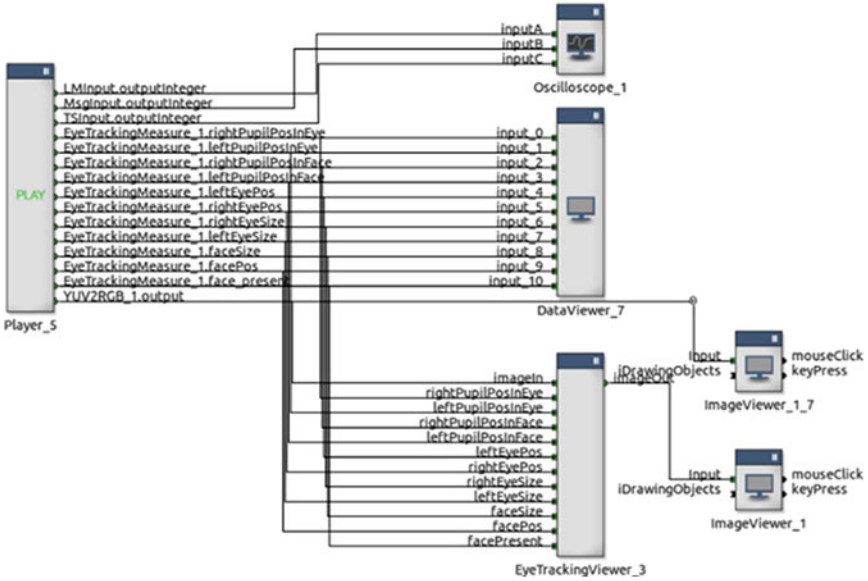


Fig. 7 Example of replay diagram

4 Proof-of-Concept Demonstrator

To study the feasibility of the aforementioned concepts, ESG has developed a demonstrator which mimes a real-life situation in automotive cockpit design process.

4.1 Demo Scenario

Let us assume an OEM is designing a cockpit looking like Fig. 8, with an instrument cluster in front of the driver, and a multimedia screen located on the central console. To use IVI (In-Vehicle Infotainment) features, the driver needs to turn his/her eyes away from the road, to glance at the central screen, and to perform some action on the HMI, such as selecting a menu item. This might generate safety hazards.

The cockpit design team is **considering two user input technologies** for selecting a menu on the IVI screen: touchscreen and gesture recognition. The team would like to know which of the 2 competing technologies causes the **least distraction** to the driver.

To do so, the team creates a test bench for UIL testing and quantitative measurement. The test environment looks like the cockpit under design, with a driver's seat. An experiment will consist in putting a person into the environment and have him/her play the role of the driver. The test campaign will include several experiments: several times for each person, and for several people who differ in sex, age, size, level of education, cultural background, etc.

The test bench hosts a prototype of the IVI application. This prototype application is representative of the final application as far as HMI is concerned:

Fig. 8 Cockpit design illustrating demo use case

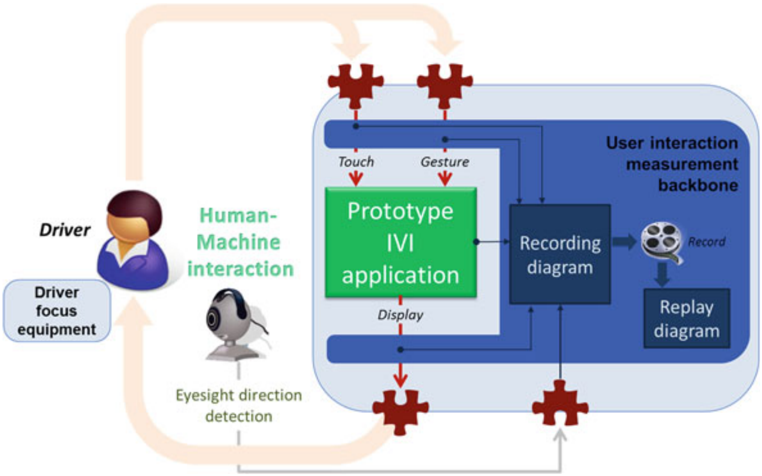


Fig. 9 Demo test bench

- user output: display on the central screen;
- user input: cursor point and click, implemented either with touchscreen or with gesture recognition.

In order to imitate real-life driving situation, the test bench includes equipment to draw the driver's attention and eyesight, as if the driver was focusing on the road.

To observe the user, the test bench includes a device which detects the driver's eyesight orientation (Fig. 9).

4.2 Demonstrator Implementation

ESG has implemented the test bench on a laptop PC running on Linux. This PC holds several roles simultaneously:

During UIL experiments

- It runs the prototype IVI application, which is developed under Qt GUI framework for easier portability. It displays the application on an external 7″ multimedia touchscreen.
- It gets user input events and forwards them to the IVI application. These events are:
  - touch events from the 7″ multimedia touchscreen;
  - "grab" gesture events detected by a COTS gesture recognition sensor.

  Both input sensors are USB peripherals.
- It observes the "driver" with its embedded webcam.

- It hosts the measurement backbone. Especially, it runs the runtime Engine and the Recording diagram.
- It acts as the driver focus equipment. To do so, it displays a game (similar to Tetris) on its main screen which the "driver" is asked to play at.
- Finally, it controls the test sequence, and provides instructions to the "driver" by displaying messages on its main screen (Figs. 10 and 11).

Fig. 10 ESG demonstrator during an experiment—with touch screen

Fig. 11 ESG demonstrator during an experiment—with gesture recognition

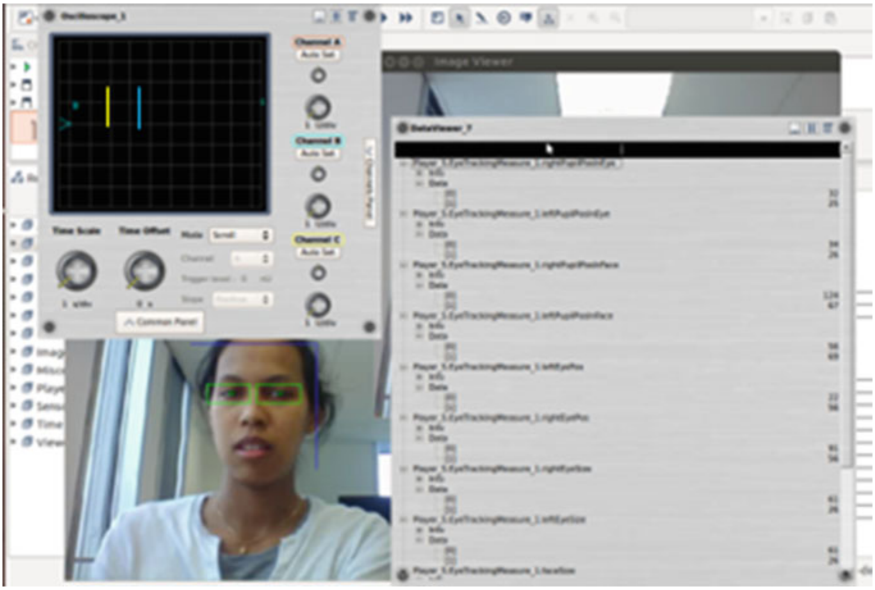


Fig. 12 ESG demonstrator—replay

After the experiments

- The PC runs the Replay diagram with the Studio, to analyse measurement results (Fig. 12).

Regarding eyesight orientation detection, ESG has integrated a simple solution consisting in applying image processing algorithms to the webcam images. These algorithms are able to detect the location of the face inside the image, and then to detect the location of the eyes inside the face. Webcam images and algorithm results are all recorded by the backbone during the experiment, in order to help analysing results during replay.

Here is the nominal experiment sequence:

1. During the whole experiment, the IVI application displays four buttons on the 7″ screen.
2. The test starts with the first use-case. Each use-case is a succession of four requests asking the driver to select four buttons. The first use-case only involves the touch-screen technology. At the same time a game is running in background to keep the driver's attention and simulate a real focusing situation. To give instructions to the driver, the PC displays a pop-up window in front of the game. Response time is measured as the time from window pop-up until the correct button is touched.
3. When the 4 instructions have been performed with the touch-screen, the second use-case starts. The exact same instructions are given, except this time the

button must be selected with a grabbing gesture captured by a gesture recognition device.

4. Once the second use-case is over, the test ends and a request popup asks the driver if he/she would like to visualize his/her average response time using gesture recognition and using the touch-screen.

By the end of this test scenario, test engineers will have a set of comparable values that enable them to compare gesture recognition against touch and determine which enables a quicker response from the user.

5 Conclusion

From a system engineer's point of view, an automotive cockpit is challenging to design because it requires collaboration between people from many different skill sets: marketing, ergonomics, human factors engineering, graphical design, mechanics, hardware electronics, GUI software development, vehicle networks, among others.

Therefore, any tool that helps so many different people work together seamlessly brings a valuable contribution to global efficiency.

ESG's concept of "HMI prototyping platform with quantitative user observation" is a step forward towards doing just that, by providing a common infrastructure which can potentially be used by all the actors of cockpit engineering. The demonstrator shows that this vision is feasible.

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Part IX

Keynote of FIEEC to CESA 3.0 Congress on Automotive Electronic Systems

Electro Technologies Play an Essential Role in Mobility, in the Economy and the Society as the Whole

Keynote of FIEEC to CESA 3.0 Congress on Automotive Electronic Systems

Eric Jourde

Abstract With the development of smaller and more cost effective electronics components, more and more applications in the consumer, but also in the automotive industry become possible. This has already led and will further lead to an increase of electronics content in vehicles and the linked infrastructure. The French industrial federation for electronics, electrics and communication, FIEEC, accompanies its members in this evolution. This paper describes in brief the interesting domains and the opportunities attached to them.

1 Presentation of the FIEEC

- The FIEEC is an industrial Federation which gathers **26 trade associations** in the sectors of **electrical, electronic, digital and durable consumer goods industries**.
- These sectors include **3000 companies** (87 % of SMEs), **420,000 employees** and a **turnover of 98 billion euros** (of which 46 % exported).
- Our industries **invest a lot in innovation**: 16 % of employees and 8 % of the turnover are dedicated to R&D.
- The FIEEC is member of the GFI, the MEDEF, the UIMM, the CGPME and ORGALIME, our European association.
- The FIEEC is **at the heart of an ambitious industrial strategy**. In fact, its industries are **innovative solution providers** answering new challenges and societal needs: renewables, energy efficiency, smart home, health, ageing population, digital infrastructure, digital confidence, **and of course mobility**.

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J. Langheim (ed.), *Energy Consumption and Autonomous Driving*,
Lecture Notes in Mobility, DOI 10.1007/978-3-319-19818-7_24

2 The Key Role of the Electro-Technologies in the Automotive Industry

In this context, the FIEEC has led during this year a **strategic reflection** with all stakeholders to define the vision of our industry in the **markets of the future** for the coming years. In fact, **the ongoing double energy and digital transition is deeply and quickly modifying our paradigms**, that means our way of thinking, creating and producing.

This strategic reflection, which was presented at the end of November during an event at the French National Assembly, has underlined **the major role of the electro-technologies to make the society smarter, so as to the stronger place of the consumer in all these evolutions**. As for other issues (buildings, energy and digital infrastructures, digital confidence, connected objects), **mobility is a good example illustrating these strong tendencies**.

What are the statements and challenges?

- the mobility, which represents a key sector of our economy, is **today developing very fast** (a 5 % growth of the number of vehicles every year) and is characterized by the emergence of new ways of moving (for e.g. multimodality);
- the development of mobility creates a **triple challenge for the society**: an energy and environmental challenge (reduction of CO_2 emissions), a societal challenge (increasing need for comfort, new applications) and a safety challenge.
- In this context, the **stronger complementarity between electrical, electronic and digital technologies** represents a key answer to these challenges and contributes to make **mobility more sustainable, safer, more intelligent, in one word smarter**.

  For example, 90 % of the innovation in the automotive industry today comes from the electrical and electronic sectors. Furthermore we can observe that around 40 % of the value of a car can be attributed to electronics (cables, connectors, microprocessors, electronic systems…).

What are the perspectives for our industries?

- **Two main conditions** seem to be necessary to capitalize on our advantages in the mobility.
  - The first condition is of course **innovation**.
  - The second one is to **lift constrains and to establish the right framework for the development of our industries** (better regulation, key role of standardization, reinforcement of the collaboration between research and industry, acceptability of the technologies…).
- In that perspective, **three main orientations** appeared for the coming years:
  - **the electromobility**, where our country is one of the leader. This is a key element of energy transition and the development of smart cities, especially

  thanks to the smart charging of electric vehicles enabling the management of electricity consumption in the building and in the city;
  - **the connected transport**. It makes the road and the trains smarter and safer, allowing thanks to embarked electronic and software systems a higher comfort and information of the consumer, a better management of the traffic and an improvement of the quality of infrastructures;
  - **the autonomous vehicle**. After the mechatronic systems, the cyberphysics systems play a growing role in the development of transports (vehicles, trains, airplanes) and are at the center of embarked technologies enabling new applications (e.g. speed control).

- To develop all these technologies in the mobility sector, there is **a need for a massive deployment of energy and digital infrastructures**.
- Furthermore, an ambitious action is appropriate at the European level to promote our vision and technologies. In this direction, the FIEEC as strongly contributed (for example with our colleague of the ZVEI) to the definition of the vision of Orgalime, our European association. **A vision paper "Technology for the World, Manufactured in Europe"** was presented to the European Commission and to Member of the European Parliament last month.

3 A Partnership with All Stakeholders

- In fact, our sectors need **to be very active at the French and European level** to promote our model to the public authorities.
- To maximize the efficiency of our action, we need **a collective approach and a stronger partnership of all stakeholders in the automotive industry**, to be at the heart of the markets of the future.