Comparison of functional integration methods from aviation and automotive industries

Norbert Neuendorf, René Knorr

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Norbert Neuendorf[1]
With kind support by Dr. René Knorr[1]

1: ESG Elektroniksystem- und Logistik-GmbH,
Livry-Gargan-Straße 6,
82256 Fürstenfeldbruck, Germany

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1. Abstract and Introduction

Both automotive industry and aviation have to put in a variety of efforts to integrate new functions into their systems that will resolve problems still unresolved. In both areas unresolved problems can especially be found where cross-linked systems are the prerequisite for solution. Current technical and functional architectures are suited for this application only in a limited way. Therefore this article will give an outlook to the future of both military and civil architectures, as they are the basis for functional integration.

2. Automotive industry

2.1 Example

On the 15th of November in 2007 a traffic pile-up occurred on the autobahn from Munich to the northward direction. After an initial crash an involved coach was at right-angles to the motor way. All lanes were obstructed; solely the breakdown lane was unobstructed. Other vehicles were approaching at high speed (Figure 1).

The driver on the middle lane was trapped between cars at his sides and the bus obstructing the lanes in front of him. An independent and accident-free solution of the situation was not possible under these circumstances. Even worse: His panic reaction involved many other cars in the pile-up. He was the point of origin for a chain reaction.

A joint solution, maybe available in the future, would have directed as many vehicles as possible over the breakdown lane, and rightly in a coordinated way. For the rest of the vehicles the solution would have been selected that would have promised the least overall damage (Figure 2).

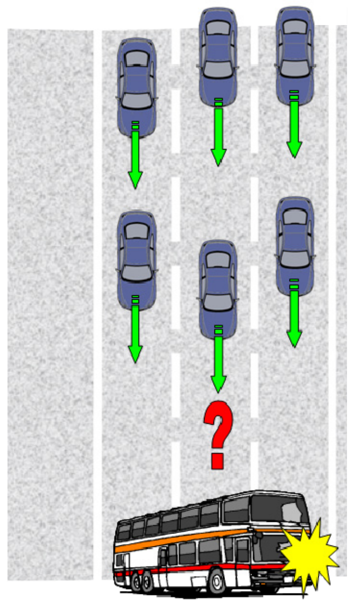

Figure 1: Situation that led to a traffic pile-up

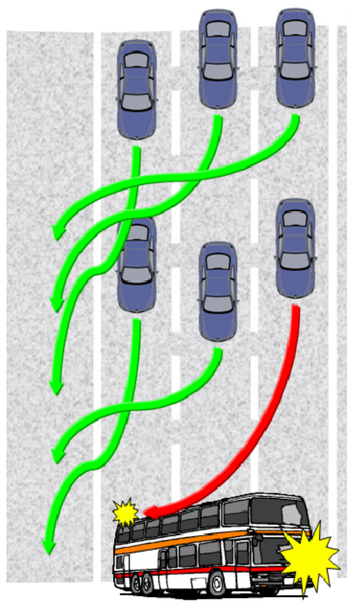

Figure 2: Avoidance of a traffic pile-up by a joint solution

The outlined advanced driver assistance system is not possible on the basis of current functional and technical architectures. Below the necessary change from today's architecture to future architecture is described.

2.2 Today's architecture

Today's architecture is characterised by unities of function, control unit and sensors/actuators (Figure 3).

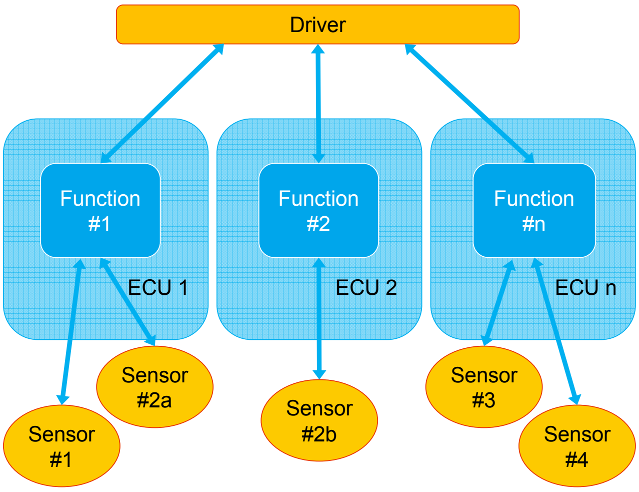

Figure 3: Today's architecture with unities of function, control unit and sensors

As a first approximation every driver assistance function is realised with a specific sensor configuration (and possibly actuator configuration) and a dedicated electronic control unit well adapted for the needs of the function. A function is executable well if all these components are present and they are working free from defects. Part of the freedom from defects is: All physical environmental conditions have to be within the ranges of the sensors. E.g. an assistance function based on a camera fails in dense fog.

The costs directly result from the combination of the aforementioned components. Thereby the sensors are often the most expensive components and so price-setting. Lower priced variants for lower market segments are created by installing lower priced sensors with inferior sensor range and/or value quality. As a result of the inferior sensor range or value quality the functionality itself is limited. Further savings potential is only possible by economies-of-scale effects.

Installing more assistant functions is accordingly identical to integrating more unities of function, control unit and sensors/actuators. A coordination of the assistant functions is realised only rudimentarily because coordination is not supported by this kind of architecture und can only be realised at great efforts. One important disadvantage of the lack of coordination is the fact that the communication of every assistant function with the driver is more or less separated from the other assistant functions. Every assistant functions uses its own communication channels. The communication happens without consideration of the current system state or even the state of the driver.

2.3 Architecture and functional integration in the future

There will be a substantial change in vehicle's architecture in the next years. The independence between function on the one side and control unit and sensor configuration on the other side is the essential difference between today's architecture and the architecture in the future (Figure 4).

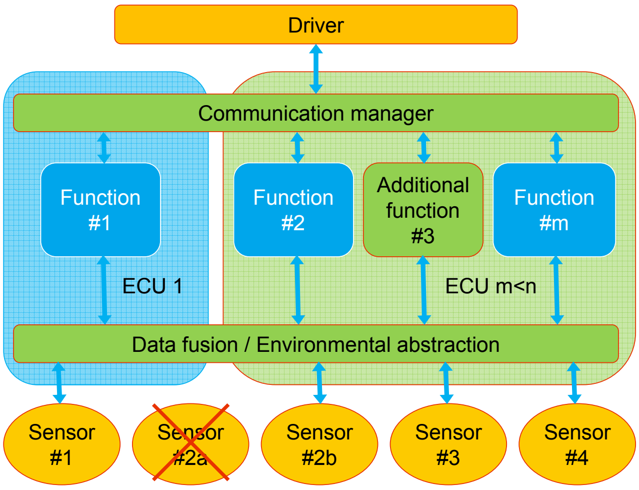

Figure 4: Architecture in the future with data fusion, environmental abstraction and communication manager

It is not valid any longer that a function is executable if its control unit and its sensors are present. In fact a function is always executable when enough system resources and the necessary environmental information are available at execution time. System resources and environmental information are abstracted from the function.

For system resources abstraction is done by open system architectures like AUTOSAR [1] or concepts that go beyond AUTOSAR like service orientated communication. The number of electronic control units will decrease. The single control unit will provide enough system resources for more than one function. If a control unit or respectively the control unit network provides sufficient capacities functions can be added without the need for integration of further control units.

For environmental information abstraction is done by concepts of data fusion. These concepts are under way [2]. Data fusion abstracts the raw data of the sensors from the functions. But it is even more important that all environmental information is available system wide for all functions. If new functions do not need additional environmental information no additional sensors have to be integrated into the system. The possibility of creating more information robustness and/or information quality by appropriate algorithms is another advantage of sensor fusion. The system becomes better in respect of system reliability and system performance. One disadvantage of sensor fusion: the higher demand for system resources. And it is not an easy task to overcome difficulties with system-wide information propagation (update rates and latency).

In summary functions can possibly be upgraded without upgrade of hardware in terms of electronic control units or sensors. Thereby the costs calculation is changed. Functions themselves obtain a value that is independent of the hardware costs. In addition to economies-of-scale effects new savings potential is created by the significantly improved ratio functions to hardware components.

Architecture in the future – new possibilities

The abstraction of functions from hardware, the thereby resulting simplified functional integration and the system-wide provision of comprehensive information provide new possibilities. They are the prerequisite for the solution of pestering problems that arise from the integration of more and more assistance functions into the car.

The automobile makes up for a trend that has been initiated in aviation many years earlier. Instead of four crew members some decades ago an airplane can be flown by two pilots and automatic systems. The accident rate in civil aviation is as low as never before. But new problems have arisen by the operation of automatic systems: Underload of pilots in standard situations and loss of skills, thereby resulting overload in non-standard situations without automatic systems by the previous loss of skills. Furthermore loss of situation awareness and loss of system comprehension by information overload. Aviation has already made the experience that an increasing automation level can make systems less safe instead more safe. Problems like “pilot-out-of-the-loop”, “mode confusion” or even “loss of situation awareness” are well known in aviation.

Car drivers will possibly meet the same problems. Today’s situation is affected by increasing demands to the driver. The driver faces an increasing system complexity by a multiplicity of driver assistance functions. Reams of assistance functions whose single or combined functionality can not be understood by the driver route much information over various information channels to the driver. Mostly this is done uncoordinated and takes care for neither the driving situation nor the system or driver state. Additionally there is an increasing situation complexity by more and more vehicles on the road. The driver can become overstrained. And overstrain on the road always means danger of accidents.

Solution to the problem is the reduction of the information overload by coordinating the information flow to the driver in dependence on situation and driver state. Information is processed actively and combined to more significant information. Results are presented at optimal point of time. Objective is the specific support of the driver in terms of an “artificial co-driver” [3].

It is not intended to create an additional driver assistance function and to increase the system complexity. It is intended to transfer a concept from aviation to automotive industry to overcome the problems mentioned above.

The communication manager of the future is the central and exclusive interface between driver assistance functions in the car and the driver. Using a single, central interface allows the creation of optimal communication: concepts for operation and information can be realised without exceptions or deviation. The “artificial co-driver” has full access to all information: It knows the system state, the driver state and out of data fusion the environmental state. All its actions are based on the knowledge of the situation and the ability to interpret the situation. A workload management as part of the communication manager determines the level of workload of the driver and the environmental condition. For example driving over a highway at good weather conditions is easier than driving in the mountains with rain or snow in the night. Depending on workload level and situation the workload management optimises the information flow to the driver. In critical situations only important, especially safety relevant information is presented to the driver. Less important information is postponed, unimportant information is omitted.

The communication manager is based on the concept of “intelligent automation” with approaches like human-based automation, cooperative automation and cognitive automation. These approaches have been implemented successfully [4] in first aviation projects. The automations have abilities that correspond to the human abilities of information processing and problem solving. Thus the driver can understand the decisions of the system.

A communication and workload manager based on cognitive automation as a driver assistant system on top of the car ensures optimal “situation awareness” by situation and driver dependent information processing and presentation.

The ability to find solutions in contradictory situations is an important advantage of the cognitive automation. Ideally a communication manager is doing a human being would do if it had enough time to think about the situation, the objectives and the different possible solutions.

Extending the communication manager beyond information presentation to autonomous action is the solution for the example of traffic pile-up mentioned above. The objectives are known (minimal damage), the situation data comes out of the data fusion and the system knows the abilities of the car and thus the options for action.

But one element is missing for a satisfying solution. The vehicles have to aggregate their selfish objectives to an overall objective. And they have to harmonise their options for action. The result is a driver assistance system that goes beyond a single car. For this purpose cars have to be equipped with appropriate communication means.

Architecture in the future – Car2X-communication

Likely communication networks of vehicles will be so called mobile ad-hoc networks.

These networks are dynamic in several respects: The number of vehicles in a communication cluster is varying, the set of vehicles is varying and the positions of the vehicles are varying.

An efficient routing of messages is necessary in such dynamic, mobile ad-hoc networks. Simple broadcast algorithms would produce to high communication costs (costs in terms of bandwidth, latency and hardware requirements). Therefore messages have to be routed through the network. Like the network the routing itself has to be dynamic and optimised continuously. Appropriate mechanisms are under investigation and development at the moment [5] (Figure 5).

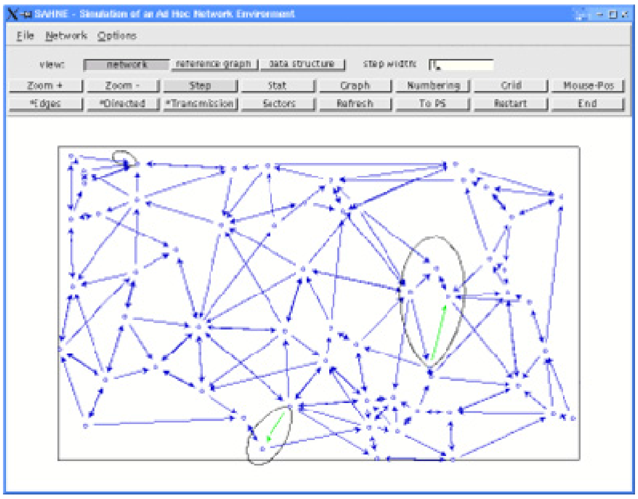

Figure 5: Simulation of a dynamic, mobile ad-hoc network at the University of Paderborn, Germany

Additionally further technological aspect have to be taken into account. A suitable transmission standard has to be used, e.g. IEEE 802.11p for the automotive sector. Furthermore the data exchange has to be secure: encryption, authorisation, authentication and redundancy are important topics. Aviation is strong with these topics. But in aviation changes are imminent too.

3. Aviation

3.1 Progress in aviation

The success of military operations is more and more depending on the joint action of all combatants. Here communication plays a decisive role too. On this basis military operations and the example of avoiding a traffic pile-up are comparable. Accordingly there must be similar solution elements. This chapter is focused on possible future communication structures in military aviation.

There are programs that deal with improvement of the communication infrastructure for military operations. Such a program is ETAP. ETAP (European Technology Acquisition Program) is designed to develop the technology required to build a future combat air system (FCAS). Within ETAP, there are several Technology Demonstration Programs (TDPs), which will each demonstrate a product from a certain discipline. “Communication/Data Link” is one of those programs.

By the way, not only military aviation is pursuing of improvement. According to Eurocontrol [6] the capacity of the existing Air Traffic Control (ATC) / Air Traffic Management (ATM) communications infrastructure is already tending towards saturation. It is expected that the existing systems in Europe will be overloaded within the next 15 years. Current ATC and ATM systems and operational procedures are seen as the bottlenecks in air transportation in the near future. These systems and services are closely linked to the functional components of Communication, Navigation and Surveillance (CNS).

For both military and civil aviation it is true that communications plays the primary role for data and information exchange among the air traffic participants. It is a prerequisite for an efficient and safe mission performance

Civil aviation is also mentioned because there is only a single airspace for both military and civil aircrafts. Military communication structures have to be interconnected with the civil ones and vice versa (Figure 6). The networks are coupled technical and functional. That’s an expansion of the architecture.

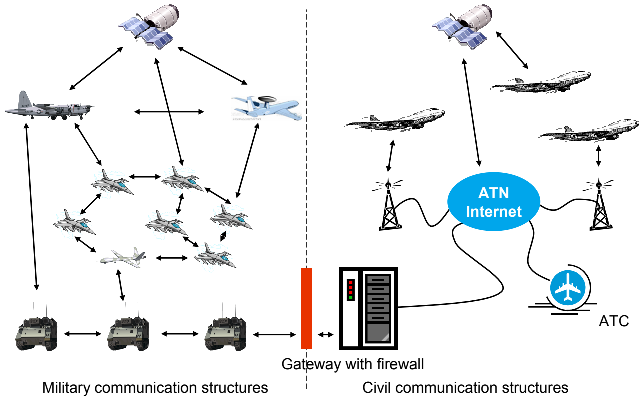

Figure 6: Interconnection of military and civil communication structures

3.2 Approach for future communication infrastructures in military aviation

Several possible concepts for the future communication infrastructures in military aviation are under discussion at the moment. One of them is similar to the automotive concept mentioned above: Every single aircraft serves as a multifunctional communication device. It acts as a relay, router and gateway in order to establish ad-hoc networking. The network is basically organised in communications clusters. A higher organisational level plans the communication between clusters or ground stations with respect to different bandwidths, frequencies, moving patterns etc. (Figure 7).

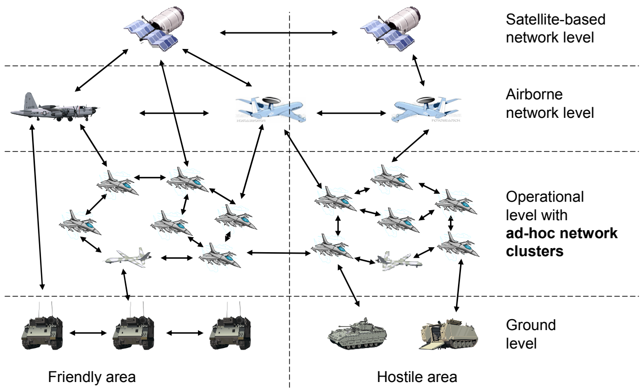

Figure 7: Ad-hoc network clusters as basis for future communication infrastructures in military aviation

There are no real backbones but satellites and command and control stations can be included as a relay or as a terrestrial network.

Architecture principles, network management and security principles

The specific tasks define the basic architecture principles. They are as follows:

- The communication nodes are not identical. They can not provide the full bandwidth of communication systems. Therefore communication resources have to be partitioned, taking into account the specific tasks of a communication node.
- It is impossible to manage a network completely ad-hoc. But the more mobile the network nodes are, the more ad-hoc a network should be.
- The network management is a central part of a network. But for security and performance reasons it should be a distributed system.

These principles are valid for both the automotive and the avionic world.

The civil avionic world knows many technologies for a network management according to the aforesaid principles. But the technologies have to be adapted to the military needs and completed with purely military technologies.

An operational network management has to ensure elementary network qualities:

- Security: Ensuring that the network is protected from unauthorized users.
- Performance: Eliminating bottlenecks in the network.
- Reliability: Making sure the network is available to users and responding to hardware and software malfunctions.

A network management is a complex system. The functions it performs include controlling, planning, allocating, deploying, coordinating, and monitoring the resources of a network, network planning, frequency allocation, predetermined traffic routing to support load balancing, cryptographic key distribution. authorization, configuration management, fault management, security management, performance management, bandwidth management, and accounting management.

Of course security management and cryptographic key distribution is essential for military applications. But future autonomous cars will need the same security level in order to prevent obstruction or misuse of functions based on ad-hoc networks.

Security Principles

NATO currently only uses symmetric key ciphering for military communication. Symmetric keys have to be provided in a logistic process. For NATO the keys are managed centrally. They are distributed by couriers and supplied to the aircrafts be special devices. On the one hand the key chain is very long, many persons have to handle the keys and automation of the key distribution can hardly be established. On the other hand in operation the keys are valid for only one day.

Central – and secure - provision of symmetric keys is therefore a very high effort. For future communication structures with much more network participants than today these procedures will not be applicable.

Future communication infrastructure in military aviation will base on asymmetric keys to avoid the disadvantages of symmetric keys. Fortunately civil data communication has a lot of experiences with asymmetric encryption keys military aviation can benefit from.

4. Conclusion

Functional development and integration are highly depending on the capabilities of the underlying architecture. We now face a change in architectures in both the military and the automotive worlds. The differences between them will become smaller and strong similarities – especially for communication structures – arise.

Future communication structures for cars as well as for (military) aircrafts will use ad-hoc networking based on clusters. Therefore it is likely they will both use similar communication architectures and security principles.

The new communication structures are the top of new functional and technical architectures. On the one hand they become more and more determinative for the functional architecture. They are the prerequisites for new functions that leave behind the tight borders of a single car or aircraft.

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