

Context-Awareness and Collaborative Driving for Intelligent Vehicles and Smart Roads

Simone Fuchs Stefan Rass Bernhard Lamprecht
Kyandoghene Kyamakya

University of Klagenfurt
Transportation Informatics, Department of Smart Systems Technologies
Universitaetsstrasse 65-67, 9020 Klagenfurt, Austria
{simone.fuchs, stefan.rass, bernhard.lamprecht, kyandoghene.kyamakya}@uni-klu.ac.at

Abstract

We discuss the importance of context-awareness in driving assistance systems (DAS). We motivate the advantages of incorporating the context in decision finding using several examples and show a hierarchical decomposition strategy for handling context information on a very general basis. The utility of collaboration is pointed out by discussing various situations and applications where co-operation can significantly contribute to a reliable context-aware situation assessment and to reasonable decisions. Early indication of dangerous situations, higher comfort of driving and better support for inexperienced drivers or for driving in a less familiar environment are only some of many benefits that are expected to arise from co-operative driving assistance systems.

Keywords: context, context-awareness, collaboration, driver assistance system, road infrastructure

1 Introduction

According to the European Transport Whitepaper [3] "transport by road is the most dangerous and the most costly in terms of human life". In the year 2000, 40 000 people were killed in the EU by road accidents and 1.7 million were injured. The estimated direct and indirect costs of road accidents are about EUR 160 billion. Most often, an error made by the human driver is the cause for fatal accidents. Only a small number of the overall accident rate is related to technical problems or system failures. One of the main objectives of the EU Transport program is the improvement of safety and the reduction of accident rates. Special interest will be given to co-operative and situation aware systems, as well as to information and communica-

tion technologies (ICT) as they are expected to bring a major boost to feasible problem solutions.

This paper is about the concepts of context-awareness and collaborative approaches related to driver assistance systems (DAS) and road side infrastructure. The first two sections define the meaning of "context-awareness" and of "collaboration" within driver assistance systems (DAS). Afterwards we propose our concept of a context-aware reasoning process and show the integration possibilities of context-awareness and collaboration between intelligent vehicles and smart roads.

2 Context-Awareness in Driver Assistance Systems

The growing pervasion of computing has brought the term "context" to focus within a variety of applications. Many definitions can be found throughout the literature, but no consensus exists so far on the meaning of "context". Thus before using the term in our paper, we first want to clarify our notion of context with respect to driving a car. We will use "context" in the understanding of "situation-awareness", as defined by Endsley [2] and cited by [1] as "... the perception of elements in the environment within a span of space and time, the comprehension of their meaning and the projection of their status in the near future". So, context for a driving assistance system means the driving situation, consisting of the environment and all objects and traffic participants within it, which are currently relevant to the own vehicle. Additionally, the driver, the state of the own vehicle and also the national driving regulations are part of the driving context. Recognition and interpretation of context is a crucial task for future intelligent DAS, which aim at supporting the driver in difficult situations. A variety of advanced DAS exist today for various tasks:

pedestrian recognition [13], traffic sign recognition [11] and adaptive cruise control (ACC) [10] are only some examples. However, current approaches are mostly stand-alone ad-hoc solutions, focusing on a highly specialized sub-task, with limited context-awareness. For the future - with the ongoing development in the fields of machine-vision and sensor technology - we expect that integration of stand-alone sub-solutions will take place, thus resulting in smarter DASs. The overall driving context will become important for recognizing and interpreting complex driving situations. DAS will become increasingly knowledge based and methods will be needed for modeling and handling the vast amount of context information.

3 Collaborative Driver Assistance Systems

A single DAS is able to master complex tasks, but it has its limits. Like for a human driver, it is not possible for an assistance system to look around corners, behind curves or knolls, or through obstacles (other vehicles, building, vegetation, etc.). To overcome this limits, vehicles in the same neighborhood should co-operate and share their information with each other. Co-operation increases the information of every participating vehicle, thus improving its decision making capabilities. With co-operation, DAS are able to achieve better performance in supporting the driver, simply because they have *additional information* about their surrounding. Also, reliability and quality of existing information can be improved, using the additional information from other sources. The available information can either be passed on to the user as a warning or used for active intervention to the driving process (also see section 5).

Another co-operation approach are infrastructure-based systems. Here, the road-side infrastructure is enhanced with sensor and communication technologies and provides information to vehicles driving past. Traffic signs with an RFID can identify themselves to by-passing vehicles. Camera systems which are monitoring intersections can transmit information about present vehicles and pedestrians to nearby cars. Traffic signals can pass on their current state and information about subsequent phases to approaching cars. These are just a few examples of what is meant by intelligent infrastructure. The vehicle-only approach has the advantage of being independent of the technological capabilities of the surrounding, thus enabling comparatively cheap systems with wide area coverage. If infrastructure technology is available, it should be integrated with existing in-vehicle information to improve data quality.

4 Hierarchical Context-Processing

The context for a driving situation consists of four major sub-contexts:

- a) the operating environment of the vehicle and all relevant objects within it,
- b) the driver,
- c) the vehicle with the built-in DAS (own vehicle) and
- d) national traffic regulations.

The most important context with the greatest variety of participating objects is the environment. By "spatial" context we refer to the physical environment (the type of the road) the own vehicle is currently driving in. The spatial context is normally valid for a time-span of minutes up to hours. The "local" context is a regional physical environment where special driving rules apply and it is located within a spatial context. Examples for a local context are intersections, level crossings, tunnel, crosswalks etc. The local context depends on the spatial context, meaning that e.g. a highway can have tunnels, but intersections and level crossing are forbidden on a highway per definition. Traffic objects like signs, pedestrians, markings, etc. are located within and valid for a spatial or local context, respectively. This model improves the scene-analysis and reasoning process, because non-likely objects and scenarios can be excluded in advance. Road conditions complement the driving environment.

The driver-context comprises the current state (tired, drunk, sick, ...), experience (beginner, expert), the risk-willingness (high, medium, low) using finite value domains and also the driver's intent for the next planned maneuver. Detection of these states with sensor systems is taken for granted, as there are already an increasing number of successful research projects in this field [14] [6] [8] [16]. For the own vehicle, built-in safety systems must be considered. Recommended driving behavior differs with presence and absence of antilock braking system (ABS) or electronic stability program (ESP). For example, in case of absence of ABS, a more cautious and passive driving behavior should be recommended, because the stopping distance will increase.

Driving regulations have been considered only to a limited extent so far, although they have substantial influence on the recommended behavior and have to be incorporated in the reasoning process. Driving rules differ between countries, so adaptation becomes necessary. Therefore, a simple and easy-to-change representation is important. Based on this considerations, we developed a high-level UML-based context-model for scenario description, identifying relevant context-objects and their relationships (cf [4]). We intent to use this model as basic domain description for development of a context-aware DAS. The number of possible objects in a driving context is comparatively low; the main challenge for a context-aware reasoning system arises from the extensive number of possible object-combinations within a traffic scene.

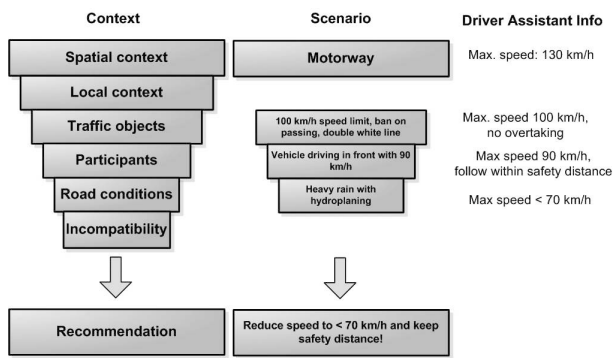


Figure 1. Example: How does context-awareness influence decisions of a DAS?

Figure 1 shows an example of how context-awareness is influencing the recommendations a DAS gives to the driver. The spatial context (type of road) dictates the applicable standard driving rules under best conditions (without other participants, without additional traffic objects, in daylight and good weather). Any other object within the context presents an additional restriction to the given standard behavior. In the example, under best conditions the DAS would only monitor the maximum speed limit. If a front-driving car with a speed of 90 km/h appears, the DAS can give the recommendation to overtake, depending on the driver's preferences (defensive or offensive behavior). Suppose now that further analysis of the scene, however, detects that we are also in a ban-of-passing and 100 km/h speed limit. Therefore, the DAS deduces to follow the car within safety-distance. Without a ban-of-passing, the recommendation would still be "follow within safety-distance", because the mandatory speed difference for overtaking (20 km/h as taught by Austrian traffic schools) cannot be legally reached within the speed limit. Additional bad weather conditions further influence the decision process. The system may propose an even lower speed (e.g. in case of hydroplaning). The last step in the presented reasoning hierarchy - "Incompatibility" - is used for determining unforeseen circumstances, which are conflicting with the current context. For example, a pedestrian on a highway or another vehicle violating right-of-way at an intersection would pose conflicting objects within the context.

This simple example shows the high influence context-awareness has on an intelligent DAS. Still, in most present-day projects, the overall context is not sufficiently appreciated. The example further shows that situations can be analyzed step-wise in a hierarchical fashion, reducing the number of possible decisions. Reasoning starts with determining the standard behavior. Additional objects detected throughout the hierarchy impose further restrictions.

In the next section we show some advantages collaboration

has on context-aware reasoning.

5 Impact of Collaboration on Context-Aware Reasoning

Most of the time, a driver will not be alone on a road or highway section, and several vehicles will perceive the same context. Therefore it is natural to exchange context information between vehicles in order to either confirm or reject current beliefs about the context, or even acquire new knowledge. As perception based on vision, roadside sensors, or in-vehicle sensors may be subject to random errors, mixing the information from multiple sources helps improving the data quality. Probabilistic techniques like Bayesian networks are one possibility of updating beliefs about uncertain information and reasoning techniques (whether these are simple fact and rule systems, fuzzy logic based expert systems, or other variants including Bayesian reasoning), can - and should - also build upon information from other sources. We shall illustrate this using several examples, where collaboration can provide significant advantages. It is useful to distinguish between measures that can be taken by an intelligent vehicle and others that can be implemented by a smart road. The following two sub-sections are dedicated to each of these aspects.

5.1 Collaboration between vehicles

Inter-vehicle collaboration in the context of this paper means the exchange of information that is generated by and for other vehicles. Examples of such information and situations giving rise to the need for collaboration are the following:

Overtaking: Suppose you are following another vehicle with no line of sight through it and you wish to overtake. You can hardly assess whether another vehicle is approaching on the other lane. If your car broadcasts your intention to overtake, then the vehicle in front can transmit its local context, and in particular, if it has yet perceived any other vehicle on the oncoming lane which is outside your field of view. This could be especially useful if sight conditions are suboptimal by the presence of fog or at turns.

Activity of in-vehicle support systems: Once a local safety system like ABS or ESP has been active, this indicates a potentially dangerous situation, either the mistake of a driver or bad road conditions. Either way, a follower as well as other vehicles approaching the section on the other lane should be notified that they may also experience similar conditions and thus a driver can be warned before getting into a dangerous situation.

Exchange of traffic objects: Once a vehicle has perceived a significant object (another vehicle, a pedestrian, a biker, etc.), it should communicate this information to its neighbors. Apart from speeding up the global perception by parallelizing this process, it can also help reducing errors, since an object that is confirmed by any other vehicle may be assigned a higher confidence value. Vehicles can notify other ones about objects (e.g. pedestrians at an intersection) they may not yet have recognized, thus enhancing the overall information about the current context. Additionally, the number of announcements of the "same" object can provide a measure of reliability that can easily be provided to a human driver.

An interesting application of exchanging this information can indeed be preventing traffic jams from growing too fast. A recent work [12] proposed a fast detection method for traffic jam fronts based on communicating the presence of a congestion to the vehicles on the opposite direction lanes on a highway, thus carrying this information in a timely manner to the followers that will see the traffic jam later on. If so warned, drivers may be able to avoid the congested areas.

Communication of negative changes in the speed: If a driver is able to accelerate, then this information can be communicated to others, however, this may be of less value than doing the opposite thing: telling followers about a sudden drop of velocity could prevent rear-end collisions, and can have a crucial impact on the (avoidance of) formation of traffic jams. Even the most basic models of macroscopic traffic simulation (one of the first has been [9]; cf. [5] and [7] for more recent overviews) exhibit shockwave phenomena, which are triggered by sudden inhomogeneities in the speed and consequently in the local traffic density. Communicating such events over an ad-hoc network of vehicles may help increasing the speed of information propagation and thus prevent shock-waves and perhaps even phantom traffic jams arising from such events. (Traffic jams that are there for no obvious reason are sometimes termed "phantom traffic jam". This often is the result of a vehicle breaking sharply, thus causing a red-light domino effect among the following vehicles. Other events can also trigger the formation of such a jam. The RAC Foundation [15] has collected the top 5 causes on their website).

Communication of local contexts and context objects:

Even if the road network is available by incorporation of geo-information systems (GIS), printed maps or knowledge of the driver, obstacles like construction sites or accidents will almost never appear on a map

that ships with a navigation system. Once a vehicle envisions a specific context (like a zebra crossing, railway tracks, closed road sections, new or even removed traffic signs, etc.) it should notify the others of the current state, so internal maps can be updated and the recent context can be considered in the hierarchical reasoning process.

Notification in cases of emergency: Whenever it happens that vehicles are in an uncontrollable state (e.g. skidding) or simply have a car break-down, others should be notified that this car is in trouble. Once a sudden break is required (such as when the motor oil indicator lamp is on), to avoid accidents others should know of this potential obstacle. Moreover, it raises the probability of seeing a pedestrian on a highway, which conflicts with the context-rules, and thus should go into any reasoning process with high priority.

Transporting all this information between vehicles requires design of reliable ad-hoc networking strategies, as well as efficient data mining strategies. As the amount of collected data may be huge in contrast to the capacity of an ad-hoc inter-vehicle network, data needs to be assessed against its value and priority before being broadcasted. Alternative strategies for message propagation may also include the road-side infrastructure, which is topic of the next section.

5.2 Collaboration between vehicles and the infrastructure

Collaboration between vehicles and the road-side infrastructure means that apart from information exchange between vehicles, there may be information that can hardly (or not at all) be gathered by a vehicle on its own. We give a few examples and situations, where information exchange between the road and a vehicle can be beneficial:

Exchange of road conditions: Road conditions can either be derived (assessed) from the activity of electronic helpers like ESP or ABS, or alternatively, sensors embedded in the road may provide this information. There are heuristic rules for deciding whether one is in danger of hydroplaning, or how to assess whether the road in front of the vehicle is icy or not. Measuring the temperature of the road, the amount of rainfall or snow, or the humidity can provide valuable information allowing drivers to choose alternative routes, if a section turns out to be icy, foggy, or if there is strong rainfall or snow. Regarding the rainfall, this information could theoretically also be derived from the activity of the windshield wipers, but in this case one needs to distinguish between cleaning the windshield and clearing it from water.

Warning in case of accidents: Car break-downs that are due to severe damage of the car may even be sufficiently bad to shut down the vehicles communication facility (or more simply, a broken battery causes all communication to fail). In this case, the breakdown triangle itself could be equipped with active beacons (or RFID transponders) telling the infrastructure that there has been a car accident. For broadcasting this information to other drivers, several architectures are imaginable, including the use of a central broadcasting server, road-side wireless LANs, ad-hoc networking between vehicles, etc.

Exchange of traffic objects: Apart from vehicles announcing the presence of traffic objects, weight sensors or RFID transponders embedded in the infrastructure can also communicate such information. Together with vehicle-based context recognition, this will provide a reliable global picture of the network utilization, that can be made visible to any participant and thus be a big asset in reasoning processes. Traffic lights can transmit information about their current and subsequent states, thus allowing the DAS to decide if to break or to pass through.

Especially the information about traffic conditions in the network can be exploited for other purposes as well. Routing algorithms that account for the current road utilizations can decrease travel times and planned routes can be communicated to other driver's DAS's, hence yielding a homogeneous utilization of the entire network.

To summarize our arguments and envisioned system at a very abstract level, figure 2 displays the loop of information exchange between vehicles and the infrastructure. By communicating information to others and receiving information from others, the global models at each participant will be iteratively updated and keep improving over time.

6. Conclusions

We have presented a variety of arguments that support the need for including the context in any decision process during driving. We have shown a hierarchical context decomposition strategy, that allows for a logical break-down of different aspects that yields to significant simplifications in reasoning processes. Moreover, we have pointed out the value of co-operation among vehicles and between vehicles and the infrastructure. In our view, tomorrow's driving assistance systems can go far beyond their present capabilities by implementing co-operation and information exchange in order to collectively perceive the context. The value of collaboration must not be underestimated and the need for making decisions dependent on the context is beyond doubt. Designers of present-day driving assistance systems already

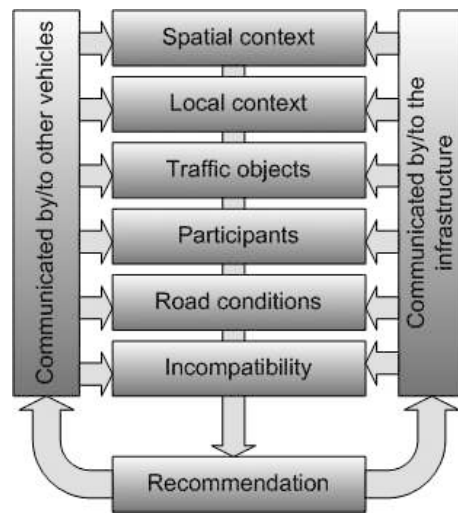


Figure 2. Schematic view on collaborative context sensing and updating.

have adopted some of the mechanisms of collaboration and context awareness, but it is still a long way to go until a fully collaborative context sensing system will be available to drivers as a standard feature. As soon as this is the case, we believe that the improvements in terms of safety, transport efficiency and comfort of driving will exceed expectations enormously.

References

- [1] M. Baumann, T. Petzoldt, and J. Krems. Situation Awareness beim Autofahren als Verstehensprozess. *MMI-Interaktiv*, (11):43–57, December 2006.
- [2] M. Endsley. Towards a theory of situation awareness in dynamic systems. In *Human Factors*, number 37, pages 32–64, 1995.
- [3] European Commission. European transport whitepaper. URL: http://ec.europa.eu/transport/white_paper/documents/index_en.htm, last access on 13/06/2007, 2001.
- [4] S. Fuchs, B. Lamprecht, S. Rass, and K. Kyamakya. Bringing Context-Awareness to Driver Assistance Systems. submitted for publication to 3rd International Symposium on Location- and Context-Awareness (LoCA 2007), Oberpfaffenhofen, Germany, September 2007 on, May 2007.
- [5] D. C. Gazis. *Traffic Theory*. Kluwer Academic Publishers, Boston, 2002.
- [6] A. Heitmann, R. Guttkuhn, A. Aguirre, U. Trutschel, and M. Moore-Ede. Technologies for the monitoring and prevention of driver fatigue. In *Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, pages 81–86, 2001.
- [7] D. Helbing. *Verkehrsdynamik*. Springer, Berlin, 1997.

- [8] Q. Ji and X. Yang. Real-time eye, gaze, and face pose tracking for monitoring driver vigilance. *Real-Time Imaging*, 8(5):357–377, 2002.
- [9] M. Lighthill and G. Whitham. On kinematic waves II. A theory of traffic flow on long crowded roads. *Proceeding of the Royal Society A*, 229:317–345, 1955.
- [10] G. Marsden, M. McDonald, and M. Brackstone. Towards an understanding of Adaptive Cruise Control. In *Transportation Research, Part C, Emerging Technologies*, volume 9, pages 33–51, 2001.
- [11] J. Miura, T. Kanda, and Y. Shirai. An Active Vision-System for Real-Time Traffic Sign Recognition. In *Proceedings of the 2000 IEEE International Conference on Intelligent Transportation Systems*, pages 52–57, October 2000.
- [12] M. Schnhof, M. Treiber, A. Kesting, and D. Helbing. Autonomous detection and anticipation of jam-fronts from messages propagated by inter-vehicle communication. *Accepted for the Transportation Research Record: Journal of the Transportation Research Board.*, 2007.
- [13] A. Shashua, Y. Gdalyahu, and G. Hayun. Pedestrian detection for driving assistance systems: single-frame classification and system level performance. In *IEEE Intelligent Vehicles Symposium*, pages 1–6, June 2004.
- [14] P. Smith, M. Shah, and N. da Vitoria Lobo. Monitoring head/eye motion for driver alertness with one camera. *15th International Conference on Pattern Recognition - (ICPR'00)*, 04:4636, 2000.
- [15] The RAC Foundation. the independent body established to take on the role of protecting the interest of the motorist. URL: <http://www.racfoundation.org/>, 2007. last access on 13/06/2007.
- [16] M. M. Trivedi and S. Y. Cheng. Holistic Sensing and Active Displays for Intelligent Driver Support Systems. *Computer*, 40(5):60–68, May 2007.