Enhancing Driver Assistance Systems by Cooperative Situation Awareness

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Abstract

Driver Assistance Systems support drivers in their task of driving a vehicle. There are various applications which work on different levels of assistance and perform different types of assistance. All these applications need some information of their current situation. Adaptive Cruise Control for instance senses the velocity of the preceding vehicle and adapts the own velocity accordingly. Currently one application senses merely its required information and performs an assessment of the situation merely on the basis of this information. By bringing Situation Awareness to the Driver Assistance System all applications have access to a suitable situation description and may assess a situation more precisely and reliably at an early stage. Cooperation of distributed Situation-Aware Driver Assistance Systems allows the exchange of information on the current situation and thus enhances the quality of the situation description.

The objective of this paper is to present the concept of Cooperative Situation Awareness for Driver Assistance Systems that enables the deployment of more sophisticated and novel applications. These future applications will increase safety and efficiency on road.

1 Introduction

Driving a vehicle is a complex task. The vehicle has to be coordinated in a longitudinal as well as a lateral direction. For longitudinal control the driver has to accelerate and decelerate, for lateral control s/he has to choose for an appropriate steering angle in order not to leave the lane. To coordinate all of these operations, the driver has to be aware of his environment. Especially vehicles in the vicinity, their velocity and acceleration, the course of the road, the road surface condition and the skills and attitudes of other drivers have to be observed and the driver operation characteristics have to be adapted to the observed circumstances.

Obviously the task of controlling vehicles efficiently without causing any accidents is far from trivial. Systems that assist the driver in her/his task of driving a vehicle are called *(Advanced) Driver Assistance Systems* [1].

There are different types of applications a Driver Assistance System may provide. A differentiation can be done by the objective focussed by the application: safety or efficiency. Whereas applications focussing efficiency support the driver in leading the vehicle with minimized resource consumption (e.g. planning the shortest/fastest route), safety applications support the driver in preventing or mitigating hazardous situations, also called Active or Passive Safety Applications respectively. Examples are navigation systems for planning an efficient route or the Adaptive Cruise Control (ACC) in order to maintain a safe distance to the preceding vehicle.

These applications use a special perspective on their current situation to make a decision. Current ACCs, for example, sense the distance to the preceding vehicle but can neither detect nor predict any abrupt changes in the environment, e.g. a vehicle changing lanes and becoming the new preceding vehicle, or any influences concerning distance adaptations e.g. due to icy roads or fog. Similar holds for navigation systems. The process of planning an efficient and safe route has to take into account the situation along the route (e.g. traffic jams, dangerous road segments). This is not a static process once initiated in the beginning of a trip, but taking steadily care of changes in the situation and adapting the route if necessary.

Current applications merely use a small and dedicated subset of information describing the situation. By having access to a shared situation description these applications profit by a more precise and reliable situation assessment and thus provide an advanced support for the driver. In order to achieve this a shared situation observation and to a certain extent a shared situation assessment is required (see red rectangle in fig. 1). The objective of this paper is to show how Driver Assistance Systems providing various applications can use a shared situation description to improve current applications and lay the foundations for novel applications.

The remainder of this paper is structured as follows. Section 2 gives an overview of Situation-Aware Driver Assistance Systems. The following section 3 presents the concept of Cooperative Situation Awareness. Section 4 shows some aspects of our implementation of the Situation-Aware Driver Assistance System. The paper ends with a conclusion in section 5.

2 Situation-Aware Driver Assistance System

For controlling a vehicle the driver has to perform an **observation** of the environment, an **assessment** of the observed information and if necessary initiate a certain **action** upon the assessment of the situation (see fig. 1). A Driver Assistance System supports the driver by these processes but it is not mandatory for the system to implement all processes.

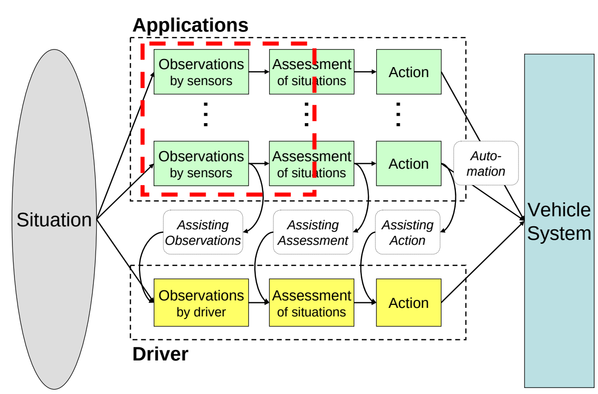

Figure 1: Support of Driver Assistance Systems

Application Types

For instance night-vision applications merely observe the area in front of the vehicle by IR-cameras and assist the driver by providing the observed picture (*Assisting Observations*). The disadvantage of this type of applications is the information overload for the driver. Usually, it is not reasonable to provide the situational information observed by several types of sensors directly to the driver. This would lead to a huge amount of information which the driver would not be able to process in an adequate time span [2].

Thus, some applications assess the observed situational information and use the results to initiate some preliminary actions (*Assisting Action*). A preliminary action would be the preparation of the brake pads if the assessment process detects a short distance to the preceding vehicle and a braking action is anticipated. The subsequent braking action initiated by the driver will be effective earlier. Others such as Adaptive Cruise Control (ACC) implement all three processes and directly interact with the vehicle system (Automation). ACC, for instance, measures the distance to the preceding vehicle (observation), recognizes if the distance is too small (assessment) and slows down the vehicle if necessary (action).

Another type of application applies observation and assessment (*Assisting Assessment*). These applications observe situational information, detect hazardous situations and present the resulting information or warning messages to the driver. Examples for these applications are Traffic Jam Warning, Curve Speed Warning, Road Feature Notification, Intersection Collision Warning, etc. [3].

Application Levels

The situation assessment targets different application levels. Analog to [4] we distinguish strategic, tactical and operational application levels.

The task of an application working on *strategic* level is to support the driver in planning a suitable route from her/his place of departure to her/his destination. According to safety aspects this route should not guide the driver into hazardous situations, regions with dangerous road conditions (e.g. slippery road surface due to freezing rain), highly congested areas or restricted zones. Whereas some hazardous situations have a very static behavior some are strongly influenced by dynamic parameters. For those it is crucial to be aware of their status, attributes and dynamics.

Applications working on strategic level focus on long-term goals. Thus strategic applications are based on a long term situation assessment and therefore less critical timing constraints. A sample instruction for the driver as a result of a strategic situation assessment may be *"Take country road B471"* in order to avoid an upcoming traffic jam on the highway.

The task of an application working on *tactical* level is the planning of maneuvers. A maneuver is a fixed recurrent sequence of operations along a planned route. It has to be stressed that the planned route is never left by maneuvers. In order to avoid hazardous situations a maneuver may be changing lane, decelerating to a certain velocity or stopping the vehicle. A sample instruction for the driver as a result of a tactical situation assessment may be *"Change to left lane"* in order to avoid bringing the driver into a hazardous situation on the right lane. For instance this may be an icy road segment, an accident or an approaching emergency vehicle.

The task of an application working on *operational* level is to control the vehicle while maneuvering. Activities on this level are called operations. For safety reasons these operations have to be coordinated to the environment. If for instance the road surface is icy an accelerating or decelerating operation that would bring the vehicle into an uncontrollable motion must not to be initiated. Operational applications have short-term goals and therefore presuppose real-time behavior. Because of these timing constraints instead of informing the driver a direct interaction with the vehicle is preferable (Automation). However, a sample instruction for the driver as a result of an operational situation assessment may be *"Avoid acceleration or braking operations"* as long as the driver is traveling on an icy road surface.

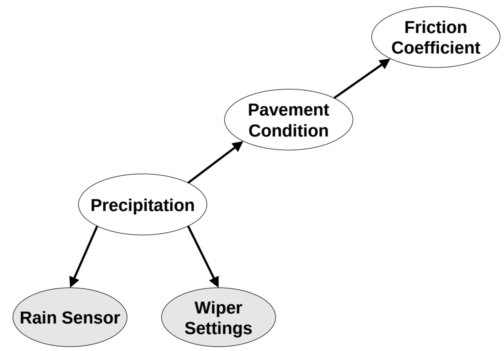

Figure 2: Causality

3 Cooperative Situation Awareness

As can be seen in the previous section, there are a lot of applications that require information on the current situation to support the driver on different levels fulfilling different goals by providing different types of assistance. For the Situation-Aware Driver Assistance System a local Knowledge Base provides this information on the current situation to every application of the system [5, 6]. The following section shows a model for the situation description and how cooperative systems interact to exchange information on the current situation.

Situation Description

In the remainder every information that can be used to characterize a situation is called *Situational Information*. Every situational information characterize a specific aspect of the situation (e.g. pavement condition, vehicle position, etc.). Estimating the states of the relevant situational information provides a suitable description of the situation.

Situational information may have some kind of basic impact on other situational information. This impact prevails without having any state estimation. This relationship between situational information is ontological [7]. It is given by our world and therefore keeps unchanged under every condition. Situational information characterizing `Precipitation`, for example, has an impact on the `Pavement Condition` which in turn has an impact on the `Friction Coefficient` for this road segment (see fig. 2). The impact is based on causality. `Precipitation` can be seen as a cause for the `Pavement Condition` and therefore `Precipitation` has an causal impact on the `Pavement Condition`.

A subset of this situational information has a causal impact on situational information which can be directly observed whereas other situational information can not be directly observed and therefore is called *hidden* for observers. According to the previous example the hidden situational information `Precipitation` has an causal impact on the *observed* situational information of a `Rain Sensor` integrated in the vehicle. Other sensors already integrated in a majority of new vehicles are for instance wheel sensors for the ABS, weight sensors to adapt the braking pressure, brightness sensors for the headlight adjustment, yaw rate sensors and steering wheel sensors for the ESP, GPS sensors for the navigation system and many more.

As described above a hidden situational information may have a causal impact on an observed situational information. But a hidden situational information may also impact more than one observed situational information, which is exemplified in figure 2. `Precipitation` has a causal impact on the `Rain Sensor` as well as the `Wiper Settings` which may be set manually by the driver.

Exploiting causal relations and the data given by the observed situational information makes it possible to draw conclusions on hidden situational information which can not be observed directly. Thus data given by the `Rain Sensor` and/or the `Wiper Settings` can be used to draw conclusions on the `Precipitation` and in the next steps also on `Pavement Condition` and `Friction Coefficient`.

Having knowledge about the current friction let the Situation-Aware Driver Assistance System adapt its behavior to the estimated friction coefficient. In this sense for example accelerating or decelerating operations can be adapted to the current friction on an operational level or regions with low friction can be avoided by the navigation system on strategic level. But this knowledge about the current friction is only valid in a certain context. The estimation is based on the sensor data provided at a certain point in time at a certain location.

In general it can be said that every situational information is valid in a certain context. Context for a situational information may be location and time, but also the pavement condition and vehicle characteristics may be crucial to specify the situational information. Exemplified that means that a friction is estimated at a certain position at a certain point in time for a specific vehicle characteristic (i.e. among others affected by tread depth) and with a specific pavement condition (e.g. on an icy, dry, oily road). Thus, the situational information is only valid within this context.

By exploiting the causal impact between situational information concerning different context, situational information can be determined without having any data for observed situational information. For example, by knowing that the pavement condition (e.g. icy) will not change abruptly over time the state of the situational information `Pavement Condition` can be estimated even without having data for the observed situational information `Rain Sensor` or `Wiper Settings` [5]. This enables to a certain extent the prediction of the state of situational information in the future. To achieve this a state change behavior of situational information due to changing context has to be known.

Situation Awareness

Endsley defines Situation Awareness as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future"* [8] whereas this work refers to *the elements in the environment within a volume of time and space* as situational information in a certain context. The meaning of our situation description is limited to causal relations between situational information. As mentioned above this enables the projection of the situational information in the future (but not limited to temporal context). Here, the question arises which situational information must the Situation-Aware Driver Assistance System be aware of.

A suitable description of the situation has to include at least all situational information that has a causal impact on the driver's task. So, any situational information that has a causal impact on the safety of the driver has to be incorporated into the situation assessment of a safety application. On a tactical level this means for instance that any situational information that influences maneuvers has to be analyzed. A situation assessment may result in:

- Preventing the driver from doing a certain maneuver
- Recommending the driver doing a certain maneuver
- Supporting the driver while doing a certain maneuver

The causal impact of situational information may be different on different assistance levels. E.g. the occurrence of freezing rain in a distance of 10 km has no (or at least a negligible small) impact for the situation assessment on tactical or operational level, but may have a significant impact on strategic level. Therefore the situational information `Precipitation` with a spatial context in a distance of 10 km has to be included in a suitable situation description, but is used only for applications working on strategic level.

Cooperativeness

The concept of cooperativeness in Situation-Aware Driver Assistance Systems constitutes their operation as a distributed system. Therefore they exchange situational information in order to obtain the maximum utility. Every single system has to decide on its own what situational information is the most valuable for the other vehicles. Therefore the Situation Awareness is essential for cooperativeness. But on the other hand cooperativeness improves the Situation Awareness because situational information that can not be observed directly by the own system but is distributed by a remote system can be incorporated into the own situation description. So cooperativeness is a basic part of the Situation-Aware Driver Assistance System.

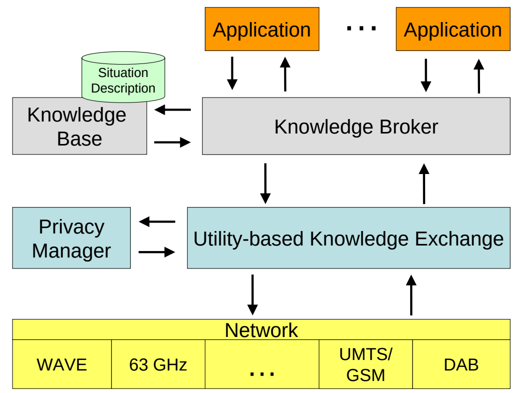

Figure 3: Architecture

4 Implementation

The implementation of our concept of Cooperative Situation-Awareness is based on the architecture pictured in figure 3. A detailed explanation can be found in [6]. This section mainly concerns the implementation of the *Situation Description* in the local *Knowledge Base* and the possibility of cooperation by using wireless networks.

Situation Description

To express a situation as mentioned in the previous section, we decided to use Bayesian Networks [9, 10]. A Bayesian Network consists of a set of nodes which represent random variables (corresponding to situational information) and directed edges representing conditional dependencies (corresponding to causal impacts). Bayesian Networks are probabilistic graphical models expressing uncertainty by probabilities. Uncertainty in vehicular environments emerges for instance due to:

- Noise in sensor data
- Insufficient temporal or spacial sensor readings

- Malfunction of sensors
- Unreliable wireless data exchange
- Manipulation by malicious intruders
- Unpredictable behavior

Therefore every node has an associated conditional probability distribution (CPD) (or prior distribution if there are no parent nodes) specified in a Conditional Probability Table (CPT) if the node represents a discrete random variable or a conditional Probability Density Function (PDF) if the random variable is continuous. These CPDs determine the causal relation between situational information. The usage of CPDs is reasonable because in most cases causal relations between situational information are not based on implication but indication. There is no stringent dependency. If, for example, the `Precipitation` shows heavy rain the `Pavement Condition` does not have to be wet in every case because it might just have started to rain, the vehicle is driving on a subterrestrial road, someone is washing the vehicle or because of a misbehavior of the sensor system. Therefore the causal dependency relies on probabilistic indication. This indication can be used to express that a set of situational information increases the probability of the occurrence of another situational information. Thus Bayesian Networks are a reasonable approach for the implementation of a situation description.

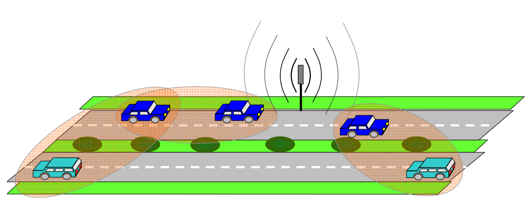

Figure 4: Situational Information Exchange

Wireless Networks

In order to work cooperatively the Situation-Aware Driver Assistance System has access to different kinds of wireless networks. Basically one has to differentiate between infrastructure based and ad-hoc networks. A promising technology in the area of ad-hoc networks for Cooperative Situation Awareness in vehicular environments is Car-2-Car-Communication [3, 11] (see fig. 4).

Car-2-Car-Communication enables the direct exchange of situational information between vehicles that are in each others communication range. Car-2-Car-Communication does not depend on any infrastructure and thus is very flexible and fail-safe. But there are also some restrictions and peculiarities compared to infrastructure based networks. Therefore the architecture permits a flexible choice of the required network type.

5 Conclusions

This paper has given an overview on Situation-Aware Driver Assistance systems and the concept of Cooperative Situation Awareness. Situation-Aware Driver Assistance Systems support the driver in her/his task of driving a vehicle efficiently without causing any accidents. This is a complex task because a lot of information has to be observed and situations have to be assessed and predicted correctly in a given period of time. Applications of a Driver Assistance Systems support the driver fulfilling different objectives on different levels and with different types of assistance.

Currently, these applications use only a small and dedicated set of information describing their situation. Observing situational information by sensors already integrated in a majority of vehicles and providing this situation description to all assistance applications enables a sophisticated assistance adapted for the current situation. This Situation Awareness also provides potentials to predict situations in the future and thereby to detect hazardous situations at an early stage. Cooperation of Situation-Aware Driver Assistance Systems by using Car-2-Car-Communication allows the exchange of situational information between vehicles according to a utility maximization.

By implementing Cooperative Situation Awareness applications are able to assess and predict situations more reliable and with a higher precision, adapt their execution to the current situation and enable an advanced support for the driver. This leads to a better driver assistance which increases the safety and efficiency on the road.

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