PROGRESS WITH SITUATION ASSESSMENT AND RISK PREDICTION IN ADVANCED DRIVER ASSISTANCE SYSTEMS: A SURVEY

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ABSTRACT

In the field of automotive safety, advanced driver assistance systems (ADAS) are receiving growing attention. Effective ADAS requires awareness of the actual driving situation, a reliable assessment of the risks, and making rapid decisions on assisting actions. This paper reviews the current progress in these complementing subfields. The goal is to explore and critically analyze the most promising technological solutions and system application concepts. In order to systematize our study, first a reasoning model is introduced. Then, a detailed study of the different situation and risk evaluation methods currently applied in automotive safety systems is presented. Our first observation has been that the general thinking about ADAS reflects a 'perception, analysis, decision and action' pattern. In addition, we observed that situation and risk assessment is typically restricted both by the number of factors considered, and by a limited consideration of drivers' attitudinal behavior. Though a huge amount of research knowledge has been published, there are still several gaps in the knowledge related to understanding and handling complex driving situations. We will use the information gathered in this survey to determine the most critical factors for ADAS, to extend risk assessment with consideration of human individual characteristics, and to develop a driver-adaptive reasoning model.

KEYWORDS

Driver-vehicle-environment arrangement, ADAS, situation assessment, risk prediction, real-time assistance, driver-adaptive reasoning.

INTRODUCTION

More than one million people die in traffic accidents every year. With the increase of vehicle usage and the frequent occurrence of complex driving situations, the number of accidents leading to injuries and fatalities has increased dramatically. Traffic-related accidents are considered to be a serious social and technological problem with global dimensions. A study made by World Health Organization (WHO) revealed that as many as 50 million people were injured and over 1.2 million fatalities occurred worldwide annually [1]. Therefore, traffic safety is considered a high priority issue not only by governmental agencies, but also by the majority of vehicle manufacturers and other stakeholders. In order to enhance the safety of mobility (travel and transportation), a number of projects have been proposed, ranging from enhancement of infrastructure to vehicle-based safety systems [2]. Conventional approaches to vehicle safety are mainly based on passive safety systems (e.g. airbags, seatbelts, pre-tensors, laminated windshields and collapsible steering columns), which try to minimize the severity of injuries caused in traffic accidents, rather than to prevent them.

In present-day vehicles, the above mentioned passive safety systems have been complemented by active safety systems, which are supposed to avoid and minimize the effects of a crash. These include electronic stability control, traction control and dedicated (forward-looking, sensor-based systems) driver assistance systems, such as adaptive cruise control, lane departure warning, collision mitigation, distance following and parking assistance. For the reason that it is better to avoid accidents than just to reduce the severity of injuries, the concept of active safety systems has received attention and solutions for advanced driver assistance systems (ADAS) has gained popularity in the last years [3]. Forecasting and prevention are receiving enhanced attention in current research, together with a continuous situation assessment and real-time risk prediction.

Commercialized ADAS have been designed based on the assessment of individual contributing factors, rather than by considering the entire complexity of driving situations and the context of driving [4]. The context of driving involves and implies complex interactions between the driver, the vehicle and the environment under varying conditions (road characteristics and properties, weather, incidental effects, etc). Most of the currently available ADAS are based on limited input information, and work mainly with partial driving contexts [5]. Limited or partial information means that not all of the characteristics of the environment, vehicle or driver are taken into consideration, and the interactions among them are not investigated comprehensively. Representative examples of these solutions are the currently marketed lateral protection systems (LPS) (which usually concerned with the lateral behavior), and speed warning systems (which mainly process information about the longitudinal behavior in the driver-vehicle-environment (DVE) arrangement).

Though a large amount of research knowledge has been produced and disseminated, there are several gaps in the available knowledge, not to mention the limitations related to complex driving situations and informed (smart) assistance. These limitations originate both in technologies and in the prevailing product/service combinations. The largest number of research and application papers has been published on some specific (popular) issues of ADAS. However, the number of papers which address these issues in their interrelationships and complexity is much smaller. Though comprehensive studies and literature surveys are being expected both by the industry and by the academia, they are missing. We also observed restricted treatments as well. For instance, the investigations of human driver behaviors did not consider concrete (and complex) real-life situations, and were reduced to stimulus-response type investigations and to driver distraction assessments [6].

Starting out from the fact that effective ADAS requires awareness of the actual driving situation, reliable assessment of the risks, and rapid decision making about the needed assisting actions, this paper reviews the current progress in these subfields. In order to be able to conduct the survey systematically, we have first developed a reasoning model. Actually, this is based on our general observation that current thinking about ADAS reflects a 'perception, analysis, decision and action' pattern. This pattern gave the basis for our reasoning model and placed situation assessment and risk prediction in a cognitive process. We believe this is important from the aspect of perceptive, cognitive and motor interactions they play a key role. The significance of this reasoning model is in the fact that it enables a comprehensive view and allows us to evaluate the constituents in themselves and in relation to each other. Furthermore, it allows the investigation of situation and risk in context. On the other hand, it does not give guidance for how to decompose the inherent complexity, though it also provides a framework for the systematization of interrelated investigations.

One of the goals of our completed study was to critically analyze the input and output factors that have been taken into consideration in the analysis of driving situation and risk, and to determine which are the most critical factors that next generation ADAS should address in their natural interrelationships (to gather information for new trajectories in future research). We will use the information gathered in this survey to extend current situation and risk prediction approaches with other factors, such as, for instance, consideration of human individual characteristics. The ultimate goal of our research is to develop a driver-adaptive reasoning model, to prototype it as a built-in driving assistance system, and to test it in practical situation. In this paper, we make an effort to explore and analyze the problems related to the development of this kind of sophisticated on-board safety solution in a holistic manner. Obviously, our survey could not cover everything. Readers interested in principles and technologies of perception must consult references [7]-[9] which present rather comprehensive reviews on environment detection. For readers interested in passive and active interventions, we point at reference [10] which gives a comprehensive review of motor vehicle warnings.

The rest of this paper is organized as follows: In the next section, we present some important studies that have been published on the components of advanced driver assistance systems. As noted above, in order to systematize our study, we underpinned it with a reasoning model which facilitates looking at both the intrinsic and the incidental interrelationships of the driver, vehicle and driving environment, rather than just at their individual roles and characteristics. Afterwards, a detailed study of different situation and risk assessment methods applied in automotive safety systems is presented. In the last section, we finally discuss our main finding related to the current state of understanding, and conclude about one of most evidential trajectory for our future research and development.

OVERSEEING SOME RELATED SURVEYS AND INTRODUCING THE APPLIED REASONING MODEL

Some related previous literature surveys

Many researchers believe that an all-embracing awareness of the instantaneously changing driving situation is the key factor for successful ADAS. They agree that this awareness can be achieved by identifying and assessing the interrelations among the driver, vehicle and the environment in varying situations [11]. This evidently introduces a complexity that needs to be addressed in its entirety, since focusing only on one of these mentioned three actors will surely not result in proper understanding and not result in advanced solutions. Contrary to this fact, most of the previous reviews report on work orientated to one particular field of the driving situation, e.g. environment detection, situation analysis, driver warnings, etc (Figure 1). They work vertically, separating the domains, instead of working horizontally, integrating the different domains. Therefore, they can be clustered according to whether they address issues related to (i) detection of the driving situation, (ii) situation analysis and judgment of hazard, and (iii) deciding on actions to be performed.

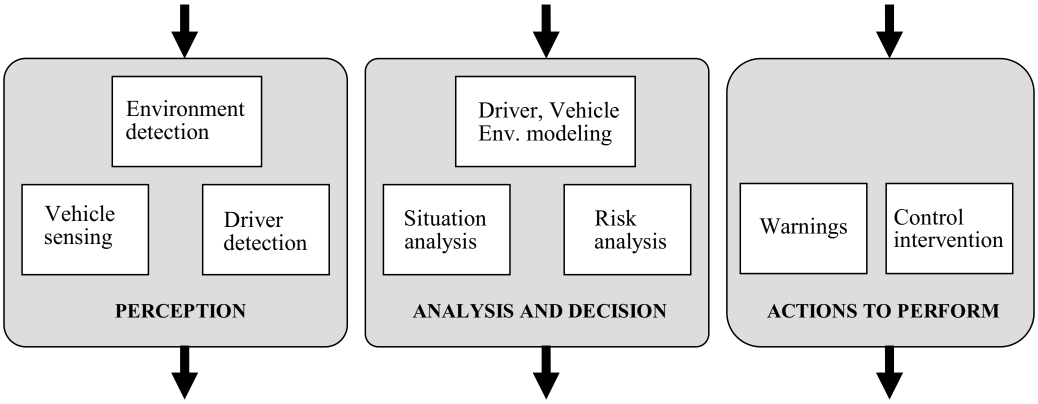

Figure 1. Advanced Driver Assistance Components

For detecting the driving situation, the study presented in [7] elaborates on the issue of detecting a vehicle in the scene. More specifically, this study discusses the problem of on-road vehicle detection using optical sensors. A comprehensive research on driver fatigue detection is presented in [12], which was mainly focusing on the technology used to detect drowsiness based on driver state and driver performance. Other studies, like [9], present a wider survey of the D-V-E arrangement, taking into consideration more factors of the observable environment, such as lane detection, obstacle detection, and pedestrian detection. In general, these studies present a partial review of the driving situation only. They consider either the environment or the driver's state, but they do not investigate the relations of these elements with other elements in the situation analysis, or at deciding on the actions to be performed. Though some studies have made effort to address the issues of combining multiple elements, e.g., detecting the driving context, analysis of conditions, and proposing actions, their number and genuine contribution are relatively low. For example, the study reported in [13] dealt with predicting collisions. This included both detection of pedestrians and modeling of pedestrian behavior. They combined pedestrian detection methods with pedestrian behavior modeling (environmental modeling) in the context of collision prediction, but they did not deal with other elements of the environment.

The literature suggests that almost all ADAS have been developed for a particular situation, and perhaps that is the reason why situation analysis and decision making was not comprehensively addressed. Our impression has been that a clear difference between the situation analysis and risk prediction has not been made. Actually, in certain paper they are not separated at all. As far as situation analysis concerned, the majority of studies concentrated on a given situation. For instance, different road departure warning systems have been considered in [14], and different driver models for particular situations have been discussed in studies [15] and [16]. We have found few studies that put the emphasis on complex situations, and tried to assess a more difficult driving arrangements, like [17], [18] and [19]. The authors of these papers considered and investigated different maneuvers for different driving situations.

The study reported in [20], made an attempt to tackle more complex situations, by identifying the relationship between the driver behavior and the risk of an accident. In this study, different variables of the longitudinal behavior (speed) and the lateral behavior (time to lane crossing) have been taken in to account in order to assess the risk reliably. Variables related to other aspects of a driving situation have not been evaluated explicitly. On the other hand, the need for more comprehensive models of risk has been generally recognized and some recent projects, such as the INSAFE – Prevent project, concentrate on advanced risk models. They include the driver, the vehicle and the environment in interaction [19].

In terms of interventions concerning the driver and the vehicle, it is well recognized in the literature that the way of intervening is a critical issue in advanced driver assistance systems. Typically, passive, active or hybrid interventions are identified. Passive intervention usually means presenting warnings for the driver. Some recent studies compared the different ways of presenting information, in order to know the effects on the driver [21]. A part of these focused on one modality only. Other studies compared different modalities, in order to be able to tell the best way of warning the driver in a particular situation [22]. There have been only few attempts, like the Adaptive Integrated Driver-vehicle Interface (AIDE) project [23], which deal with an integrated interface useful in different situations.

On the other hand, in the field of active intervention, many more options have been considered. The focus of these studies vary from longitudinal control, such as the automatic braking presented in [24], to lateral vehicle control, such as the solution for lane keeping of vehicles, proposed in [25]. Hybrid approaches combining warning and intervention seem to be step-child in the literature. Furthermore, our feeling has been that there is a lack of studies in the literature, which would review different intervention strategies for advanced driver assistance systems. Moreover, studies are also scarce related to intervention that is based on detection of the driving situation, comprehensive situation analysis, evaluation of the hazard, and decision on the best strategies.

Introducing the reasoning model applied in the rest of this paper

We believe that, in order to be able to address driver assistance in its complexity, a comprehensive reasoning model is needed. This reasoning model is supposed not only to identify the main constituents, but also to define the logical and procedural relationships among them. As our forerunning analysis indicates, we are also in lack of these abstracts comprehensive reasoning models, which can even be instantiated on multiple levels of concreteness and details. This reasoning model is also supposed to explain what consequences including or excluding a particular element has on the driving situation, and on the safety of driving. By doing so, this would provide a robust theoretical basis for the systematic investigation and development of ADAS.

Driving can be interpreted both as a situated problem solving process and as a complex information processing process involving perception, cognition and action control. To develop our reasoning model, we considered the second one as more expressive. It can integrate the main constituents of a driving situation, i.e. the driver, the vehicle and the environment (including the road) with the generic phases of completing driving, i.e. perception, analysis, decision making and action. These are graphically represented in Figure 2, which also shows a possible decomposition to second level functionalities. This reasoning model can be developed into lower level functional models, structural models, information flow models, process protocol models, and human-system interaction model. In the context of this paper, we will use this reasoning model as the conceptual framework of our specific literature study. It has to be mentioned that we will not consider all constituents and elements of ADAS in this paper. We will focus on what belong to our current research interest, namely, the state of the art in situation assessment and risk prediction. At the same time, we will

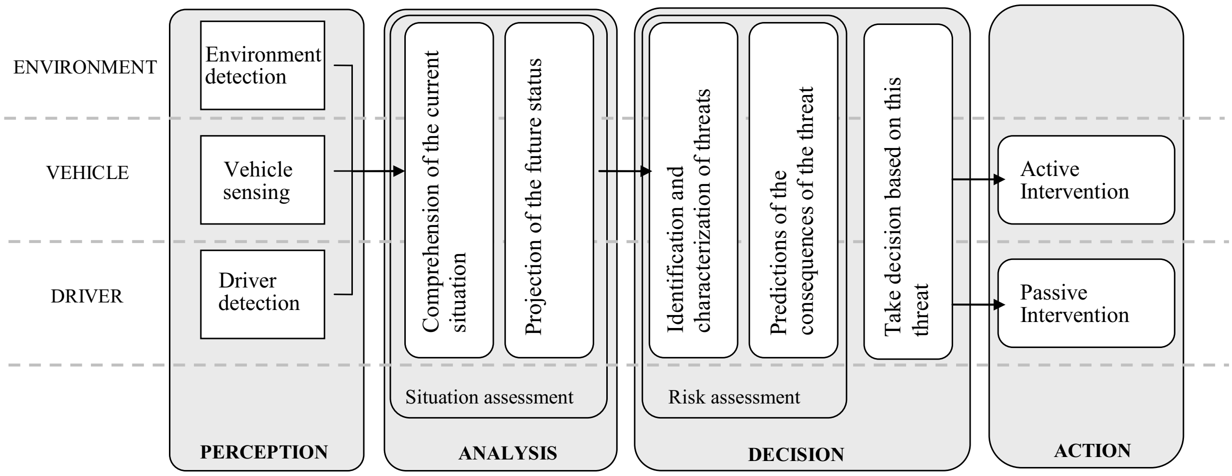

Figure 2. Generic reasoning model of driving assistance

consider the other components and important relationships at discussing the mentioned two topics.

We can show that the reasoning model can be applied to current advanced driver assistance systems. They usually incorporate modules that (i) perceive the driving circumstances and context, (ii) analyze the driving situation and conditions, (iii) consider hazard, its consequences, and possible (re)actions, (iv) perform actions. The perception module is to detect the environment and to extract information about it, the status of the vehicle, and the conditions of the driver. It usually performs the sub-processes for monitoring, detection and classification of the information, for recognition of elements (objects, people, events, environmental factors) and their actual states (position, orientation, conditions). The situation analysis module is to achieve the comprehension of the situation and to project it to the whole of the driving arrangement and process. The decision module is dedicated to risk prediction. This module identifies the threats and the consequences of that threat in order to make proper decisions and action plans. Finally, the action module is responsible for generating warnings for the driver and for the execution of the corrective actions, depending on the level of risk.

SITUATION ASSESSMENT AND RISK PREDICTION

From an information processing point of view, situation assessment requires the integration of multiple pieces of information and the determination of their relevance to the underlying goals. From the perspective of comprehension, the emphasis is no longer put on the environment, vehicle and driver individually, but on the relationships among the detected objects. Comprehension also means combination of the sensed descriptive information with general knowledge (physical rules and behavioral patterns). This allows capturing the situation as it evolves, i.e., a projection from the actual situation to future possible situations (based on the arrangement and dynamics of the elements). Basically, this comprehension and projection of the situation is what is usually called situation assessment. To support this information sensing and inference process towards optimal situation awareness, various models and methods have been developed [26]-[28].

Though traditionally seen as completely different activities, situation assessment and risk prediction are in fact closely interrelated in ADAS. Essentially, situation assessment involves two major actions: (i) object assessment and (ii) relationship assessment. The former involves reconstruction of detected or assumed objects in scenes. The latter involves identification of instantaneous relations and the changes of the relations in the driving context. The relationships may be between entities of the same type (vehicles), or between different types of entities (the road and the vehicle). Situation assessment can provide answers to questions such as: “What is the position of the front vehicle relative to the following vehicles?”, or “Which lane is occupied by vehicles?”.

Risk prediction concerns the identification of threats, determination of the type of threats, assessment of the severity of the threats, estimation of the probable effects and impacts, and the prediction of the preventive actions as an outcome of different situations in the environment. The main questions addressed are: “How dangerous is this situation?”, “What happens according to the worst case scenario?”, etc. Risk prediction has been based on various inference techniques such as mathematical, logical, case-based and procedural reasoning. Most often the goal is to achieve a quantified value of the risk (or danger), rather than just to provide a quantitative (semantic) description.

In the next section we are going to address the major issues and describe the way the situation and risk is managed in current Advanced Driver Assistance Systems. We intend to articulate the different approaches used in some representative ADAS to analyze driving situations and to predict and measure the risk.

Some issues of assessing driving situations

In the driving context, the situation assessment establishes a view of the driving situation in terms of the observed activities, events, locations and maneuvers of other objects and ego-vehicle[1] and from this view infers what is happening or going to happen on the driving situation. The driving situation assessment is responsible for identifying the relationships between the elements (ego-vehicle, lanes and detected objects) of the road environment [27]. This includes (i) determination of the performed maneuver not only by the ego-vehicle, but also by the objects detected around the vehicle, (ii) identification of the moving objects and classification of their position with respect to the projected position of the ego-vehicle in the future, (iii) determination of the driver intention, (iv) determination of the distraction of the driver, and (iv) prediction of the probable trajectory of motion.

One of the most common situations that have been analyzed in the literature is road departure. There are many alternatives to determine a departure situation. Most of the systems that have been developed are rule-based system where a descriptive or indicative variable is compared with a threshold value. The considered simplest variable is the lateral offset (roadside-rumble strips), that is, the distance between the left border of the road and the center of the front bumper of the subject vehicle [42, 43]. Other approaches like the one presented in [44] use the time-to-lane-crossing (TLC), which is a measure of the time remaining before a vehicle moving on a given trajectory will depart the road. In general the TLC provides more time for warning than the lateral offset but sometimes this prediction can be wrong because its calculation only takes into account the vehicle’s trajectory and omit the driver’s behavior. This can easily lead to a more number of false alarms. In order to avoid these situations, [45] proposed an extension of the TLC and the lateral offset, allowing the driver to drift beyond the lane boundary using a virtual lane adjusted by a learning phase. Others, like [46],

[1] Throughout this paper, ego-vehicle refers to the vehicle being equipped with a safety system.

presented a system that was called fuzzy logic-based virtual rumble strip (VRBS). Fuzzy logic offered the benefit to reason qualitatively about the vehicle's lateral position and its lateral velocity to determine the chance of departure. Among the recent studies, [47] reported that TLC is not sufficient to determine departure situations, because larger values of TLC may even be expected in case of high values of longitudinal speed and/or due to excessive lateral displacement of the vehicle, or unfavorable dynamics on the road. For this reason, they proposed to use not only the vehicle lateral position and lateral dynamics, but also the longitudinal speed limitation.

Other situation that has been commonly assessed is the speeding in curves (that is, on horizontally curved roads). The conducted investigations compared the actual speed with the maximum authorized speed in curves. The maximum safe speed in a curve depends on the road geometry, the surface conditions, the skill (or tolerance for discomfort) of the driver and the roll-over stability of the vehicle. The developed experimental systems presented different models to calculate this authorized speed. The simplest model considered only the curvature of the road and assumed a vehicle moving at constant speed on a circular section [48]. Other approaches, like the one presented in [44], took into account the super-elevation of the road and the driver behavior. In recent studies, even more precise models are used. The model presented in [49], considered a relatively accurate description of the road (the curvature, the super-elevation, the slope, and the maximum available friction), as well as the driver behavior.

Regarding the consideration of the driver in assessing driving situations, some researchers worked out situation assessment algorithms that can estimate driver distraction by continuously monitoring and evaluating the steering actions of the driver [50], the head pose, the body posture [5], the electroencephalographic (EEG) characteristics, and the heart rate. Others have analyzed eyes gaze [12]. This approach is rather obvious, but has a major drawback , namely, that the eyeballs must be detected in order the gaze vector can be calculated. This is particularly difficult, when the driver is wearing reflective eye glasses, or when the lighting conditions are dynamically changing, or when the lighting causes lighter or darker shadows on the driver's face. In order to avoid these happenings, recent studies have focused on the face orientation [51], the occupied position and posture [5].

With the intent of managing more complex scenarios, studies have been done related to the reasoning both about the future motion of the ego-vehicle and about the motion of the other participant in a road scene. Some people applied probabilistic logic-based algorithm to predict the future location of vehicles in a specific on-road environment [52]. Others, used Monte Carlo simulation-based prediction to generate a probability distribution for the possible future motion of every vehicle in the scene, in order to find the safest path to avoid the danger [53, 54]. Others elaborated on the prediction of actions with dynamic Bayesian network. They could predict maneuvers 1.5 s before the actual maneuvers [55, 56].

Most probably it has become clear for the reader by now that most of the preventive (active safety) systems developed so far are focusing only on single slice of the road around the given vehicle. There are only few efforts, like in the PREVENT project [19], to develop a more integrated approach putting together different safety systems. This integration does not mean that a safety zone would be created, as a final holistic functionality of a vehicle, but an extended safety zone is produced by joining different systems. What can be expected is that due to the rapidly evolving ubiquitous sensing technologies, sensors will in the future be covering practically all areas outside and inside the vehicle. This way, they will increase the accuracy of the car-grounded perception of the road, the road-side environment, the objects moving close to the vehicle in the neighboring area, but they will also enable a close perception of the driver's activities inside the vehicle. Obviously, to make a good decision is not enough to comprehend what is happening around but also to understand the situation inside the vehicle. The smart sensor systems have the potential to achieve a high fidelity in situation awareness both inside and outside the vehicle.

Some issues of assessing risk in driving situations

Risk prediction represents the estimation of the impacts and the consequences of the current activities of all entities in the driving context. Approaches existing in contemporary ADAS for recognizing or avoiding dangerous situations are usually not generic and do not allow for integrating background knowledge [57], i.e., these approaches are often specialized in performing one single task (e.g. warning the driver that a lane change must be dangerous or warning about over speeding in curves). In these approaches, the warning level is just determined comparing a variable for example the measured speed (of the ego-vehicle) with a maximum authorized speed [47]. With this information they establish the severity of the situation.

In an intent to define a more concrete metric for risk, some people have used a risk function [58]. This function processes the situation parameters and estimates an instantaneous level of risk. The risk is associated to an event and is defined as the probability that an event will occur multiplied by the severity of this event (collision). The problem with this approach is that they only consider one event (road departure) so the severity is attached to this single event.

Other approaches like the collision mitigation define the risk as a possible collision scenario. The risk prediction algorithms used, try to predict the future states of the vehicle involved in the traffic situation and estimate the effort to avoid the accident [50]. Commonly they try to assess one kind of threat and take action when that specific threat is detected [59]. To characterize the emergency level of this dynamic situation, quantitative measures such as time-to-collision (TTC) [60], predicted minimum distance, predicted time to minimum distance [61] and required deceleration [62] are used. In recent studies the risk is estimated by determining the effort needed to avoid a collision by either steering or braking [50]. These approaches only take one threat into account and not the threat of multiple objects in the road scene like [63]. Here, they move from a deterministic model to a stochastic model that can find threats by predicting the path of different objects using a Monte Carlo simulation. This is a more complete approach in the sense that multiple objects in the environment are considered and the fact that threats that are not necessarily connected to a particular safety function can be detected. A main disadvantage is that certain driver behavior like distraction or way of driving is not considered.

In other studies like the research presented by [64] they proposed a model of risk that integrate contributing factors of the situation (environment, vehicle and driver) and past crash records. Five risk levels are defined and the contributing factors (wet road, inattention, alcohol, etc) for each crash risk level are used to determine risk. The advantage of the model is that the crash risk is determined from the contributing factors, hazard locations and pattern of crashes, the disadvantage is that is not clear how the movement of other objects in the scene can affect the risk like in the approaches above.

Our general observation is that the definition of a risky situation is still unclear. A lot of people have defined the driving risk as a collision but what about the consequences of this collision? Although some people have explored the driving risk from different aspects, a comprehensive model of risk level have not yet been proposed, especially when the driver factors are involved. The risk involves not only the consequences to the vehicle or to the driver but also the consequences in terms of possible damage, severity to property, environment and people. Thus, to define the risk level it is useful to take into account not only the consequences over the ego-vehicle but also the consequences on the different elements that belong to the driving context and the influence of the driver behavioral aspects.

DISCUSSION

In this section, we discuss from the review the input and output factors considered in situation and risk prediction, their grade of importance and the relationships built until now between these input and output factors. In case of general driving situations, it the literature is clear that all the input factors taken into consideration can be clustered in the 3 main components of the driving context: driver, vehicle and environment.

Among the input factors that have been included from the aspect of driver for analyzing situation and risk, we can find: the body parts like the head, torso, arm/leg, eyes and eye lids, the whole body posture, the electroencephalographic (EEG), the heart rate, age of the driver, the experience of the driver and driver intoxication. According to the literature the most influential ones are the body parts like the head pose, eyes and body posture and the less considered in ADAS are the age of the driver and intoxication levels. These last factors have been considered a lot but more for studies in hazard perception and the ability to control the vehicle.

From the vehicle, the list of input factors used are the lateral speed and acceleration, longitudinal speed and acceleration, steering angle, yaw rate, pedal position, brake pedal depression and age of the vehicle. In ADAS, the most influential are the lateral speed and acceleration, longitudinal speed and acceleration, steering angle and the yaw rate. Of course, the use of these factors depends in the situation analyzed. The age of the vehicle is well considered as an influential factor in risk but in the literature there is not clarity on how to consider this in the safety models.

Regarding the environment, the input factors that have been considered are the lane (curvature, super-elevation, slope and the friction), road infrastructure as guard-rails, traffic signs, traffic lights and emergency signs, weather conditions (snow, ice, fog, rain, storm, illumination conditions), incidental happenings (other vehicles, pedestrians, animals or objects in the road). Among these factors, the lane is one of the most studied and important to consider when we are talking of analyzing situations and assessing risk. Depending on how accurate the model is, people take into account more or less parameters related to the lane. Other factors from the environment that have great influence in the situation analysis and are considered very important are the other vehicles in the scene and pedestrian. The last one has been less studied than the other vehicles in the scene. But it is considered to be a notable factor when we contemplate the risk.

It has to be noted that despite some people consider these factors in the analysis of situations, the models used for the motion of these elements are still non realistic in the sense that they do not reproduce the complete behavior of a pedestrian and vehicle. It also has to be clarified that the complexity to predict pedestrian and other vehicle behavior is high, so simplifications has to be used when real-time is a prominent issue. Regarding this issue some questions arise: Are these simplified models providing the complete information for the actual and future situations? How can we introduce realistic models without sacrificing performance? Is there any balance? These are still open issues for further research.

Furthermore, from these environment factors, the less considered in ADAS are some of the weather conditions like snow or fog. Despite some of them are covered in friction models, the need of specialized instruments and sensors in the road, makes them more difficult to implement in real applications. It is evident that people try to assess situation insensitive to these conditions but the amount of sensors needed inside the vehicle and the processing of this amount of information constitute a big problem when real-time computation is considered.

Now that we brought up the input factors, let's discuss the output factors found in the literature according to situation or risk. The most prominent output factors according to the review done are outputs related to driver distraction, driving maneuvers for road departures and collisions. In the driver distraction, the big focus in the literature is in driver fatigue and driver alertness. Activities performed inside the vehicle are also important but less explored than the previous ones. Regarding the driving maneuver, the most common ones are the lane change and path prediction. These factors are the most crucial ones when talking about situation analysis. When risk is considered, the focus is in collisions with other objects in the scene like vehicle or pedestrians. The most assessed situation is the consideration of risk with only one object in the scene. The introduction of other objects in the scene, have been only considered by few researchers but this research item is crucial when assessing the total risk in a driving situation.

From the aspect of the input and output factors, of equal importance are the relationship built until now between these inputs and outputs. We can summarize these relationships as driver characteristics (input factors) and driver distraction (output factors); driver characteristics + environment (input factors) and driver state (output factors); vehicle + environment (input factors) and driving maneuvers (output factors); vehicle + environment and collision (output factors).

A common approach in the literature is the relation between driver characteristics (input factors) and driver state. Here, it is common to see relations such as eye gaze and driver attentive focus; eye closure and driver fatigue; head nodding, head motion and driver fatigue; monitoring eyes and driver level of vigilance; Brain waves and drowsiness; heart rate and drowsiness; head – torso – arm/leg and driver activities. More complex approaches relate head position, eye gaze, pupillary change, eye closure with driver alertness. It is clear that the use of multiple visual cues reduces the uncertainty and the ambiguity present in the information from a single source but it can drastically change the computational time for processing the amount of information which is a critical issue in real-time systems. These previous relationships mostly focused in the inside information of the vehicle.

It is clear that a combination between the surroundings of the vehicle (environment input factors) and the input factors related to the driver produce better accuracy in the determination of driver state. An intent to incorporate this was the European project AWAKE [65] which employed driver state measures including eyelid movement, changes in steering grip and driver behavior including lane tracking, use of accelerator and brake and steering position to detect driver vigilance. Despite some of the environment aspects where considered like the lane, rain, fog and light there is still possibility to include other aspects that were not covered like the influence of obstacles, pedestrian and other vehicles in the scene. But again, the balance between complexity to enhance the system and real-time computation is an open issue.

Another relationship commonly studied is the relation between vehicle factors, environment factors and driving maneuvers. Most of the research focuses only in certain aspects of the vehicle and the environment to define the driver intention. In this field we found relations between predicted minimum distance of ego-vehicle from lane marking, time to lane crossing (TLC), ratio on lane curvature and ego-vehicle curvature, distance from an object in an adjacent lane, type of road (highway, rural road and construction area), type of lane markings and the intent to change the lane. Some approximations only relate one of these inputs with the intent to change lane using simple deterministic approaches, others try to gather all of them in order to reduce the ambiguity using the Dempster-Shafer theory to represent degrees of uncertainty and ignorance. These are interesting approaches in the sense that several factors from the vehicle and environment are covered but the information related to the driver, which influence the maneuvers and the risk in a situation, is forgotten. In contrast, some researchers covered also the driver aspect including factors as the head pose in order to infer more accurately the intention to change the lane and reduce the false alarms [5]. The 3 component of the driving context: environment, vehicle and driver are covered but other aspects from the driver such fatigue and some important aspects of the environment like the objects in other lanes are not included. Again, our finding is that researches try to reduce the number of factors gradually in order to reduce complexity gaining performance.

Similarly, relationships between vehicle, environment factors and collision are studied. It has been noted from the review that risk in driving situation is linked to imminent collision that can cause injuries to parties involved. That is why most of the risk prediction is done in the collision scenarios. Most of them use deterministic methods that predict single future trajectories for the objects and use this to compute measures like the time to collision (TTC) or acceleration required. In the information collected, the driver has no great influence. He/she can be distracted and that is not adding anything to the risk model.

Recent approaches used probabilistic methods to cover a more complete scenario not only following single trajectories of objects to detect one threat but computing several trajectories to detect general threats [63]. Monte Carlo sampling, a high computationally demanding technique was used. Despite it was claimed that reaching real-time performance regarding computational complexity seems feasible, it is still in experimental phase. Driver aspects like visibility constraint are included but it is still not enough information from the driver to be conclusive about the risk. Again, our main observation is that complexity is a constant issue in all the approaches, even when complex situations are considered, the complexity has to be reduced decomposing the problem into sub-problems like in the INSAFE Prevent project [19] which developed multiple safety applications and then tried to integrate them in one platform.

CONCLUSIONS

The large number of factors and data that have to be considered to maintain a safe driving situation indicates that we are facing a complexity. In order to cope with this complexity, many researchers have tried to reduce the number of parameters or try to create new associations. Covering the problem in a holistic manner is still complex due to the amount of information that has to be processed.

Nevertheless, besides the complexity involved, some issues must be carefully considered in the risk analysis such the driver factors related to distraction and behavior. We believe that consideration of the individual characteristics of drivers will play a critical role in the development of next-generation ADAS. The current orientation of research efforts indicated that not only the stimulus-response type behavior of the driver is an important aspect in terms of accidence avoidance, but also the personal character and driving attitude of the driver.

Therefore, inclusion of driver individual characteristics when assessing collision scenarios seems to be a promising future research trajectory. As we discussed, at inferring the probability of collision and at the development of general logical and technical frameworks for ADAS, only the critical elements of the vehicle and the environment have traditionally been taken into account. A new generation of ADAS could be developed if we had instrumentation for detecting the personal characteristics of the drivers in the vehicle, if we consider his/her driving individual characteristics in the situation assessments and risks estimations, and if we adjust the safety features (passive warnings and active intervention) accordingly. This adaptive ADAS could in turn reduce the number of false alarms. Towards this end, first we have to actively learn the way the driver behaves when he/she is driving a particular vehicle, and then to correlate the observed behaviors with risk factors. In other words, there is a need for a predictive characteristic model of drivers that can be used for estimation of the risk, and ultimately for driver sensitive safety automation.

Seeing the rapid development of acting-on-a-distance sensor and measurement technologies, we can expect that ubiquitous vehicles sensors will provide much more information in the near future than nowadays, and they will be able to feed embedded information processors even with contextual information in real time. The high computing capacity of on-board computers and ad-hoc networking are also expected to offer new opportunities. These will enable a fast and accurate monitoring of the driver and perception of the environment, as well as real-time assessments of driving situations and contexts. In combination with a better risk prediction and situation-sensitive decision making, these can revolutionize our thinking about future ADAS solutions, and can reduce the total number of accidents on roads.

REFERENCES

[1] M. Peden, R. Scurfield, D. Sleet, D. Mohan, A. A. Hyder, E. Jarawan, and C. Mathers, *World Report on Road Traffic Injury Prevention*. Geneva, Switzerland, 2004.

[2] A. Beutner, J. Nilsson, A. Polychronopoulos, M. Netto, D. John, and S. Martini, "SAFELANE a prevent project," 2007.

[3] R. Bishop, "Intelligent vehicle applications worldwide," *IEEE Intelligent Systems,* vol. 15, pp. 78-81, 2000.

[4] S. Glaser, A. Rakotonirainy, D. Gruyer, and L. Nouveliere, "An Integrated Driver-Vehicle-Environment (I-DVE) model to assess crash risks," 2007.

[5] M. M. Trivedi, T. Gandhi, and J. McCall, "Looking-in and looking-out of a vehicle: Computer-vision-based enhanced vehicle safety," *IEEE Transactions on Intelligent Transportation Systems,* vol. 8, pp. 108-120, 2007.

[6] M. Tsogas, A. Polychronopoulos, N. Floudas, and A. Amditis, "Situation refinement for vehicle maneuver identification and driver's intention prediction," in *FUSION 2007 - 2007 10th International Conference on Information Fusion*, Quebec, QC, 2007.

[7] Z. Sun, G. Bebis, and R. Miller, "On-road vehicle detection: A review," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 28, pp. 694-711, 2006.
[8] V. Kastrinaki, M. Zervakis, and K. Kalaitzakis, "A survey of video processing techniques for traffic applications," *Image and Vision Computing,* vol. 21, pp. 359-381, 2003.
[9] M. Bertozzi, A. Broggi, M. Cellario, A. Fascioli, P. Lombardi, and M. Porta, "Artificial vision in road vehicles," *Proceedings of the IEEE,* vol. 90, pp. 1258-1270, 2002.
[10] V. L. Neale and T. A. Dingu, "Motor vehicle warnings," in *Handbook of warnings*, M. S. Wogalter, Ed.: Lawrence Erlbaum Associates, 2006.
[11] M. R. Endsley, "Theoretical underpinnings of situation awareness: A critical review," *Situation Awareness Analysis and Measurement,* pp. 3-32, 2000.
[12] Q. Wang, J. Yang, M. Ren, and Y. Zheng, "Driver fatigue detection: A survey," in *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, Dalian, 2006, pp. 8587-8591.
[13] T. Gandhi and M. M. Trivedi, "Pedestrian collision avoidance systems: A survey of computer vision based recent studies," in *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, Toronto, ON, 2006, pp. 976-981.
[14] M. Gonzalez-Mendoza, B. Jammes, N. Hernandez-Gress, A. Titli, and D. Esteve, "A comparison of road departure warning systems on real driving conditions," in *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, Washington, DC, 2004, pp. 349-354.
[15] C. C. Macadam, "Understanding and modeling the human driver," *Vehicle System Dynamics,* vol. 40, pp. 101-134, 2003.
[16] M. Plochl and J. Edelmann, "Driver models in automobile dynamics application," *Vehicle System Dynamics,* vol. 45, pp. 699-741, 2007.
[17] A. Polychronopoulos, C. Koutsimanis, M. Tsogas, and A. Amditis, "Prediction of unintentional lane departure using evidence theory," in *2005 7th International Conference on Information Fusion, FUSION*, Philadelphia, PA, 2005, pp. 1396-1403.
[18] J. M. Nigro, S. Loriette-Rougegrez, and M. Rombaut, "Driving situation recognition with uncertainty management and rule-based systems," *Engineering Applications of Artificial Intelligence,* vol. 15, pp. 217-228, 2002.
[19] M. Schulze, T. Mäkinen, J. Irion, M. Flament, and T. Kessel, "Prevent final report," PReVENT Consortium 2008.
[20] S. Jamson, R. Batley, V. Portouli, V. Papakostopoulos, A. Tapani, J. Lundgren, Y.-H. Huang, E. Hollnagel, and W. Janssen, "Obtaining the functions describing the relations between behaviour and risk," 2004.
[21] Y. C. Liu and M. H. Wen, "Comparison of head-up display (HUD) vs. head-down display (HDD): Driving performance of commercial vehicle operators in Taiwan," *International Journal of Human Computer Studies,* vol. 61, pp. 679-697, 2004.
[22] J. J. Scott and R. Gray, "A comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving," *Human Factors,* vol. 50, pp. 264-275, 2008.
[23] J. Engstrom, J. Arfwidsson, A. Amditis, L. Andreone, K. Bengler, P. C. Cacciabue, W. Janssen, H. Kussman, F. Nathan, J. Valldorf, and W. Gessner, "Towards the automotive HMI of the future: Mid-term results of the AIDE project," *Advanced Microsystems for Automotive Applications 2006,* 2006.

[24] D. B. Maciuca, J. C. Gerdes, and J. K. Hedrick, "Automatic Braking Control for IVHS," *Proceedings of the International Symposium on Advanced Vehicle Control (AVEC 1994),* 1994.
[25] M. S. Netto, S. Chaib, and S. Mammar, "Lateral adaptive control for vehicle lane keeping," in *Proceedings of the American Control Conference*, Boston, MA, 2004, pp. 2693-2698.
[26] C. Matheus, M. Kokar, K. Baclawski, J. A. Letkowski, and C. Call, "SAWA: An assistant for higher-level fusion and situation awareness," *Proc. SPIE,* 2005.
[27] A. Polychronopoulos, A. Amditis, U. Scheunert, and T. Tatschke, "Revisiting JDL model for automotive safety applications: The PF2 functional model," in *2006 9th International Conference on Information Fusion, FUSION*, Florence, 2006.
[28] J. Ivansson, "Situation assessment in a stochastic environment using bayesian networks," in *Department of Electrical Engineering*: Linköping University, 2002.
[29] J. Edlund, M. Gronkvist, A. Lingvall, and E. Sviestins, "Rule-based situation assessment for sea surveillance," 2006, p. 624203.
[30] M. L. Hinman, "Some computational approaches for situation assessment and impact assessment," *Proceedings of the Fifth International Conference on Information Fusion,* pp. 687-693, 2002.
[31] S. Das, R. Grey, and P. Gonsalves, "Situation assessment via Bayesian belief networks," *Proceedings of the Fifth International Conference on Information Fusion,* vol. 1, pp. 664-671, 2002.
[32] N. Okello and G. Thorns, "Threat assessment using Bayesian networks," *Proc. Sixth International Conference on Information Fusion,* vol. 2, pp. 1102-1109, 2003.
[33] S. Das, "Situation assessment in urban combat environments," in *2005 7th International Conference on Information Fusion, FUSION*, Philadelphia, PA, 2005.
[34] L. R. Liang and C. G. Looney, "Decisionmaking with fuzzy-belief-state-based reasoning," in *Proceedings of the 2004 IEEE International Conference on Information Reuse and Integration, IRI-2004*, Las Vegas, NV, 2004, pp. 553-558.
[35] D. J. Dailey, P. Harn, and P.-J. Lin, "ITS Data Fusion," Washington State Transportation Commission 1996.
[36] S. Vacek, T. Gindele, J. M. Zo?llner, and R. Dillmann, "Using case-based reasoning for autonomous vehicle guidance," in *IEEE International Conference on Intelligent Robots and Systems*, San Diego, CA, 2007, pp. 4271-4276.
[37] C. H. Liu, L. S. Chen, and C. C. Hsu, "An association-based case reduction technique for case-based reasoning," *Information Sciences,* vol. 178, pp. 3347-3355, 2008.
[38] C. G. Looney and L. R. Liang, "Cognitive situation and threat assessments of ground battlespaces," *Information Fusion,* vol. 4, pp. 297-308, 2003.
[39] S. H. Chen, A. J. Jakeman, and J. P. Norton, "Artificial Intelligence techniques: An introduction to their use for modelling environmental systems," *Mathematics and Computers in Simulation,* vol. 78, pp. 379-400, 2008.
[40] P. B. Bill, *Genetic Algorithms*: IEEE Computer Society Press, 1992.
[41] R. Laxhammar, "Artificial Intelligence for Situation Assessment," in *School of Computer Science and Engineering*. vol. Master Stockholm, Sweden: Royal Institute of Technology, 2007.
[42] M. Chen, T. Jochem, and D. Pomerleau, "AURORA: A vision-based roadway departure warning system," in *IEEE International Conference on Intelligent Robots and Systems*, Pittsburgh, PA, USA, 1995, pp. 243-248.
[43] W. Kwon and S. Lee, "Performance evaluation of decision making strategies for an embedded lane departure warning system," *Journal of Robotic Systems,* vol. 19, pp. 499-509, 2002.

[44] D. Pomerleau, T. Jochem, C. Thorpe, P. Batavia, D. Pape, J. Hadden, N. McMillan, N. Brown, and J. Everson, "Run-off-road collision avoidance using IVHS countermeasures - Final report," *Technical Report,* vol. DOT HS 809 170, 1999.
[45] P. H. Batavia, "Driver-adaptive lane departure warning systems," *Driver-adaptive Lane Departure Warning Systems,* 1999.
[46] T. Pilutti and A. G. Ulsoy, "Fuzzy-logic-based virtual rumble strip for road departure warning systems," *IEEE Transactions on Intelligent Transportation Systems,* vol. 4, pp. 1-12, 2003.
[47] C. Sentouh, S. Glaser, S. Mammar, Y. Bestaoui, and B. Lusetti, "Adaptive Lane Departure and Curve Negotiation Warning System," in *8th International Symposium on Advanced Vehicle Control (AVEC'06)* Taipei, Taiwan, 2006.
[48] V. Aguilera and S. Glaser, "Data requirements for enhanced digital maps in an advanced curve-speed warning system," *Transportation Research Record,* pp. 109-118, 2004.
[49] S. Glaser, L. Nouveliere, and B. Lusetti, "Speed limitation based on an advanced curve warning system," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Istanbul, 2007, pp. 686-691.
[50] M. Brannstrom, J. Sjoberg, and E. Coelingh, "A situation and threat assessment algorithm for a rear-end collision avoidance system," in *Intelligent Vehicles Symposium, 2008 IEEE*, 2008, pp. 102-107.
[51] J. Pohl, W. Birk, and L. Westervall, "A driver-distraction-based lane-keeping assistance system," *Proceedings of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering,* vol. 221, pp. 541-552, 2007.
[52] C. Schlenoff, R. Madhavan, and S. Balakirsky, "An approach to predicting the location of moving objects during on-road navigation," *Proceedings of the Workshop on Issues in Designing Physical Agents for Dynamic Real-time Environments: World Modeling, Planning, Learning, an Communicating at the International Joint Conference on Artificial Intelligence (UCAI-03),* pp. 71-79, 2003.
[53] A. Broadhurst, S. Baker, and T. Kanade, "Monte Carlo road safety reasoning," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Las Vegas, NV, 2005, pp. 319-324.
[54] H. Cheng, N. Zheng, X. Zhang, J. Qin, and H. Van De Wetering, "Interactive road situation analysis for driver assistance and safety warning systems: Framework and algorithms," *IEEE Transactions on Intelligent Transportation Systems,* vol. 8, pp. 157-166, 2007.
[55] I. Dagli, M. Brost, and G. Breuel, "Action recognition and prediction for driver assistance systems using dynamic belief networks," in *Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science)*, Erfurt, 2003, pp. 179-194.
[56] I. Dagli and D. Reichardt, "Motivation-based approach to behavior prediction," in *Intelligent Vehicle Symposium, 2002. IEEE*, 2002, pp. 227-233 vol.1.
[57] A. D. Lattner, I. J. Timm, M. Lorenz, and O. Herzog, "Knowledge-based risk assessment for intelligent vehicles," in *Integration of Knowledge Intensive Multi-Agent Systems, 2005. International Conference on*, 2005, pp. 191-196.
[58] V. Aguilera, S. Glaser, and A. Von Amim, "An advanced driver speed assistance in curves: Risk function, cooperation modes, system architecture and experimental validation," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Las Vegas, NV, 2005, pp. 807-812.

[59] S. Danielsson, L. Petersson, and A. Eidehall, "Monte Carlo based threat assessment: Analysis and improvements," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Istanbul, 2007, pp. 233-238.
[60] E. Dagan, O. Mano, G. P. Stein, and A. Shashua, "Forward collision warning with a single camera," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Parma, 2004, pp. 37-42.
[61] A. Polychronopoulos, M. Tsogas, A. Amditis, U. Scheunert, L. Andreone, and F. Tango, "Dynamic situation and threat assessment for collision warning systems: The EUCLIDE approach," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Parma, 2004, pp. 636-641.
[62] R. Karlsson, J. Jansson, and F. Gustafsson, "Model-based statistical tracking and decision making for collision avoidance application," in *Proceedings of the American Control Conference*, Boston, MA, 2004, pp. 3435-3440.
[63] A. Eidehall and L. Petersson, "Statistical threat assessment for general road scenes using Monte Carlo sampling," *IEEE Transactions on Intelligent Transportation Systems,* vol. 9, pp. 137-147, 2008.
[64] S. Chen and A. Rakotonirainy, "A crash risk assessment model for road curves," 2007.
[65] A. Polychronopoulos, A. Amditis, and E. Bekiaris, "Information data flow in AWAKE multi-sensor driver monitoring system," in *IEEE Intelligent Vehicles Symposium, Proceedings*, Parma, 2004, pp. 902-906.