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A Probabilistic Framework for Collision Avoidance in AutomobilesUsing GSM

Sneha Miriam Abraham, Nirosha.S.V, Rathina Priya.M, Nanammal.V
PG Scholar, Department of Electronics & Communication Engg
Assistant Professor, Jeppiaar Engineering College, Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai-119
***Corresponding author: sneha.abraham16@gmail.com**

ABSTRACT

This paper is concerned with the problem of decision making in systems that assist drivers in avoiding collisions. An important aspect of these systems is not only assisting the driver when needed but also not disturbing the driver with unnecessary interventions. Aimed at improving both of these properties, a probabilistic framework is presented for jointly evaluating the driver acceptance of an intervention and the necessity thereof to automatically avoid a collision. The intervention acceptance is modeled as high if it estimated that the driver judges the situation as critical, based on the driver's observations and predictions of the traffic situation. One advantage with the proposed framework is that interventions can be initiated at an earlier stage when the estimated driver acceptance is high. Using a simplified driver model, the framework is applied to a few different types of collision scenarios. The results show that the framework has appealing properties, both with respect to increasing the system benefit and to decreasing the risk of unnecessary interventions.

Index Terms: Automotive safety, collision avoidance (CA), decision-making, driver modeling, threat assessment.

INTRODUCTION

Road traffic accidents are one of the world's largest public health problems. In the European Union alone, traffic accidents cause approximately 1.8 million injuries and 43000 fatalities each year. To reduce these numbers, vehicle manufacturers are developing systems that can detect hazardous traffic situations and actively assist road users in avoiding or mitigating accidents. Systems that assist drivers in avoiding collisions are becoming increasingly more common and are even being introduced as standard equipment in some passenger cars. Collision avoidance (CA) systems can generally be divided into three layers, as shown in Fig. 1. Measurements from on-board sensors, such as accelerometers, cameras, and radars, are processed in the first layer and then interpreted in the second layer, which makes decisions on when and how to assist the driver. The third layer executes the decision, e.g., by automatically applying the brakes of the vehicle.

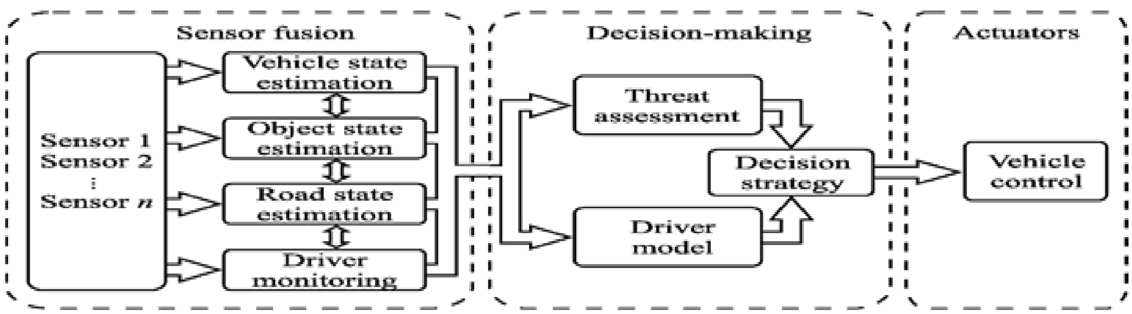

Figure.1.Proposed CA System

This paper focuses on decision-making strategies in the presence of measurement and prediction uncertainties. The framework is applied to a threat assessment algorithm and a model that estimates if the driver judges the situation as critical. These are jointly evaluated when making decisions for interventions. The measurements contain random errors, and consequently, the vehicle and object state estimates that are obtained in the sensor fusion layer are associated with uncertainties. A threat assessment algorithm utilizes these estimates to make predictions of road-user trajectories. Based on these predictions, an assessment is performed to estimate if and how a potential accident can be prevented. Both the state estimates and the predictions are associated with uncertainties that need to be treated properly. Moreover, to obtain a high customer acceptance, it is important that the system also accounts for the preferences of driver, such that the driver is not disturbed by the system during normal driving conditions. The aim of CA systems is to assist drivers in avoiding collisions with other road users and objects, without triggering interventions that the driver may consider unnecessary. Clearly, to autonomously avoid a collision, an intervention must be triggered while an accident is still avoidable.

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However, most collisions that can be avoided by CA systems *possibly* can also be avoided by a skilled driver. This implies that there is no way of telling whether the driver would have been able to handle the situation without the system intervening. That is, there is no objective measure available for judging whether an intervention was useful or whether the driver was disturbed by the system. It is only the driver of the vehicle that can decide whether an intervention was motivated or not. Hence, when making decisions on when the system shall take action, there is always a tradeoff between making a successful intervention and the risk of disturbing the driver. This highlights the need of incorporating a driver model in the CA system, such that vehicle safety can be further improved by enabling earlier interventions in traffic situations that the driver judges as critical.

This paper is concerned with decision-making in CA systems in the presence of uncertainties. Several probabilistic decision-making algorithms have previously been proposed, in these approaches, the risk of a false alarm is balanced with the confidence that an autonomous intervention is actually needed to avoid a collision. The term "false alarm" is, in these cases, typically defined as an intervention per-formed, although there would not have been a collision. From the driver's point of view, however, a more relevant definition would be an intervention performed that the driver regarded as unnecessary. In this paper, we propose to simultaneously evaluate the driver acceptance of an intervention and the necessity thereof, as shown in Fig. 1. To formally deal with uncertainties in measurements and predictions, we propose that decisions on when to assist the driver are made by taking a Bayesian approach to estimate the following:

1) How a collision can be avoided by an intervention;
2) The probability that the driver of the vehicle will consider the autonomous intervention as motivated.

The framework enables interventions to be initiated at an earlier stage when there is a high probability that the driver will consider an intervention as justified. In this way, the benefit of CA systems can be increased without disturbing the driver of the vehicle. Moreover, to reduce the risk of the driver getting used to having interventions, and starting to rely too much on the system, interventions are not initiated until a significant action is needed to avoid a collision. To put the framework into context, a previously presented threat assessment algorithm is used as a base to assess how a collision with a single road user can be avoided. Similar to, the framework enables this assessment to be performed in a probabilistic way, such that uncertainties in object state estimate and predictions are accounted for. More importantly, in contrast to previous research, the framework also estimates the driver's perceived threat considering both the inherent measurement uncertainties as well as uncertainties within a model of the driver's assessment of the traffic situation. To exemplify this, we introduce a simple model of the driver's threat assessment and apply it in the proposed framework. This paper is organized as follows. Section II provides the motivation for this paper and shows that a small change in the decision timing can have a significant impact on the benefit of CA systems. Section III outlines the problem formulation and Section IV describes the decision-making framework. Section V presents the modeling choices made in the specific implementation used to evaluate the framework in this paper. Section VI describes, based on these modeling choices, how the decision-making framework can be realized. Results are presented in Section VII, where the realization is evaluated on a few different types of collision scenarios, using both simulated and authentic sensor measurements. Conclusions are presented in Section VIII.

MOTIVATION

Here, we describe how this paper is related to previous re-search on driver models and show, through an example, that sys-tem benefit is strongly affected by the timing of interventions.

A. Related Literature: Goodrich and Boer propose that CA systems should account for not only the capabilities of the vehicle and the sensor system but also the autonomy and preferences of the driver. Benefit and cost functions are introduced to make decisions based on a tradeoff between the potential benefit of an intervention and the cost of disturbing the driver with an unnecessary intervention. Although the concept of using cost functions is appealing at first glance, this concept has some potential drawbacks that are pointed out. For example, the cost of an unnecessary intervention may be difficult to define and relate to the benefit of avoiding a potential collision. Hence, the behavior of the CA system may be hard to predict, and the tuning of the system could become problematic. We propose that the probability that the driver intends to apply the brakes shall be estimated and that interventions shall be inhibited if the driver intends to brake. The intent to brake is predicted by using a camera that monitors the driver's pedal usage and a camera that monitors the driver's face. Although a foot camera may be used to predict whether the driver intends to apply

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the brakes, it is probably difficult to predict whether the driver intends to steer. The driver may also be drowsy or cognitively distracted; in which case, the driver's intent could be difficult to predict, even if the driver has placed a foot on the brake pedal. Moreover, in traffic situations where the driver intends to brake to avoid a collision, it is reasonable to assume that the driver may consider a brake intervention as motivated and, thus, as not disturbing. Rather than trying to solve the difficult problem of estimating the driver's intent or the cost of disturbing the driver, the presented framework aims only to estimate whether the driver will consider an intervention as justified. In this way, driver autonomy can be maintained by only allowing the system to act when it is estimated that the driver has high acceptability for interventions.

B. Impact: As mentioned in Section I, one of the aims of this paper is to formulate a decision-making framework that can be used to improve the intervention timing of CA systems. What additional benefit is expected if the intervention timing is improved by a fraction of a second? This question is investigated through an example.

Assume that a vehicle equipped with a CA system is driving at an initial speed v_0 and that automatic emergency braking is initiated with timing such that the speed is reduced to v_c before colliding with a stationary object. How much earlier does the braking have to be initiated to fully avoid a collision? In all CA systems, the deceleration will eventually reach a constant value *a* and a collision is avoided if

$$s = \frac{v^2}{\frac{c}{2a}} \text{ -----1}$$

Where extra meters are available to bring the host vehicle to a complete stop. The time to travel this distance, before braking

Problem formulation: Let x^h_k be a state vector representing the state, i.e., position, velocity, etc., at discrete time instance t_k of a vehicle hosting a CA system. Similarly, let X_k^t be a state vector describing the state of all other objects of interest, e.g., other vehicles or pedestrians in the vicinity of the host vehicle given noisy observations on these states collected up to the current time t_k, denoted as $Y_{1:k}$ an intervention decision rule for avoiding accidence without disturbing the driver is desired.

Decision-Making Strategy L: As previously mentioned in Section I, we propose to simultaneously evaluate the driver acceptance of an intervention and the necessity thereof. Furthermore, we propose to do so in a probabilistic decision framework considering two sets of hypotheses. The first set captures the driver acceptance (*driver hypotheses*). The second set describes the necessity for the CA system to initiate an autonomous intervention to autonomously avoid an accident (*system hypotheses*). This latter hypothesis set is used to manage the risk that the driver gets used to having interventions and, hence, may start to rely on the fact that the system will avoid all accidents. When assessing the driver acceptance, we argue that the driver has a high acceptance for interventions if *the driver judges* the traffic situation as critical when an intervention is initiated.

In situations where the driver is distracted, we argue that the driver will become alert if an intervention is triggered and hence be able to judge if the situation is critical or not.

Criticality Assessment: A vital component in a CA system is the ability to detect and assess the criticality of the current traffic situation, i.e., *threat assessment*. In the literature, there are many different approaches to do this, and good examples can be found in. Similar to many of these methods, we argue that a situation is judged as critical by an *actor*, i.e., to the driver or to the CA system, if the actor is unable to find a safe escape path. Let there be a set of *n* objective physical measures, denoted as $\{\alpha_1 \ldots \alpha_n\}$, describing the criticality of different types of potential evasive maneuvers by an actor. These measures could be based, e.g., on TTC metrics or on the needed use of available tire-to-road friction to avoid an accident. Each measure α_i corresponds to a specific type of evasive action by the actor, e.g., emergency braking, passing to the side of the threat, or using a combined braking and steering maneuver. Maneuver *i* is defined as critical by the actor if the measure exceeds some limit, The situation as a whole is defined to be judged as critical if all of these measures, *individually*, are judged as critical. To put it differently, the situation is critical to the actor if the actor judges that there is no safe escape path.

When assessing the measures, we argue that they should be evaluated in themselves, independently of all other measures, and not jointly as in many other applications. A short example illustrates when the latter approach fails to assess whether there is a safe escape path or not. Let a vehicle approach a pedestrian walking with constant speed across the road and let there be two measures α_1 and α_2 representing how difficult it is to pass either to the left or to the right of the pedestrian. If the actor does not know exactly how fast the pedestrian is walking, then α_1 and α_2 are correlated as shown. In practice, this means that it is relatively easy to pass either to the left or to the right, depending on how fast the pedestrian is walking. That is, the probability that both measures jointly exceed their respective limits is very small, and under this measure, the situation would be classified as noncritical. However, the actor needs to actually make a choice of whether to steer to the left or to the right of the pedestrian, but being uncertain about the pedestrian's walking speed, it is equally unsafe to make either of these choices. That is, there is no safe escape path available.

To summarize, by evaluating the measures independently from each other, the situation is correctly classified as critical. The same reasoning is applicable when determining whether both the driver and the system judge the situation as critical. Since the driver and the CA system may have different capabilities to avoid an accident, e.g., by performing different types of actions, the two actors will assess the situation independently from each other and make separate decisions on whether the situation is critical or not. For example, the CA system may only be able to brake, whereas the driver may steer, brake, and accelerate.

System Hypothesis: For the CA system hypothesis, we propose to assess the danger in a situation by calculating a set of n_c measures, describing how difficult it is for a CA system toavoid a collision. Each measure α_i is calculated by a function designed for a particular type of evasive action, e.g., emergency braking, as shown in the following.

WhereX_k^h describes the host vehicle state at time k, and $X_{k:K+N}^t = \{X_{K+1:K+N}^t\}$ is the future trajectory of all other objects between time k and K+N. In the tracking literature, these objects are denoted as targets, a term we use when it is needed for clarity. Function $g_i^c$is assumed to be known, as discussed earlier and exemplified in section V-B. Given an initial stateX_k^t, we assume that $X_{K+1:K+N}^t$ can be described using a known statistical model. Where W_k^c is a noise process describing the uncertainty in the motion of the object.

The situation is assessed as critical in the system hypothesis if it is estimated that the system is running out of options to safety avoid an accident. That is, if each type of evasive action by the system is separately assessed as too risky or too difficult to perform with respect to the measureα_i. Using the expression in (7), a critical situation is detected if

$$\alpha_i > \alpha_i^{lim} \forall_i = 1 \dots n_c$$

Where $\{\alpha_i^{lim}\}_{i=1}^{n_c}$ are feature specific design parameters typically specifying some critical limit of the measure. The clear advantage of this approach is that the design parameter can be related to physical properties, such as desired speed reduction for a collision mitigation system when evaluating TTC. Additionally, different features can set different thresholds depending on timing and intrusiveness of the intervention, eg., a warning feature can have a lower threshold than an autonomous braking feature.

CONCLUSION

In this paper, we presented a probabilistic framework for decision-making in CA systems. We introduced a simple model for estimating if the driver perceives the situation as critical enough to justify an intervention. The results show that the use of this model has several appealing properties. Specifically, the driver model enables the system to perform earlier interventions in situations where the future trajectories of other road users are believed to be difficult for the driver to predict. Moreover, the proposed framework formally handles both measurement and prediction uncertainties both when estimating the driver acceptance of an intervention and when estimating if the CA system can prevent a collision.

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