DRIVER MODELS TO INCREASE THE POTENTIAL OF AUTOMOTIVE ACTIVE SAFETY FUNCTIONS

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ABSTRACT

This paper describes how the potential of some automotive active safety functions depend on the used driver model.
It is shown that by including a more advanced driver model, it is possible to enhance the use of the signals from different sensor systems to let the active safety function intervene earlier and smoother so that the drivers are disturbed less, and the chance to avoid an accident increases.

1. INTRODUCTION

Automotive active safety functions warn or intervene in critical situations to help the driver avoid or mitigate accidents. During normal driving, when the driver has the situation under control, the active safety functions are at rest. A function with intrusive interventions can be irritating and disturbing if it intervenes when the driver has the situation under control. Hence, such events must be avoided and this is the motivation to the paradigm to allow an intervention only if drivers cannot avoid the accident themselves. The task to decide if the driver needs assistance is called *threat assessment*, see e.g., [*1*], [*2*], and the paradigm indicates that knowledge of the capability of the driver is essential for a good threat assessment algorithm. The threat assessment module is a signal processing unit where the traffic situation is assessed by using e.g. vehicle models and driver models in combination with signals that describes the current state of the vehicle and the surrounding objects.

For example, effective collision avoidance technology is based on the ability to predict the near future. In a timeframe of less than 1 second, the future can be predicted well using vehicle kinematics or vehicle dynamics models, but at larger prediction horizons, the driver behaviour starts to play a dominant role. E.g. the risk for collision with an object 400 m ahead of the vehicle is almost solely dependent on the driver behaviour. When one can predict the driver behaviour one could potentially judge whether the driver intends to brake, steer or accelerate to avoid a collision or not. In case it is judged that the driver has no such intentions, warning or automatic interventions could be applied much earlier, thereby improving the benefit of the intervention without increasing the risk of disturbing the driver with unnecessary interventions.

The discussion and the conclusions in this paper build on three examples where successively more advanced driver models are being used. The first example considers autonomous braking in rear-end collisions and no driver model is included. Instead it is assumed that maximum braking and steering can be realized immediately. With this description, there is a theoretical possibility to avoid a collision very late by steering and, hence, the autonomous braking can start only when this theoretical chance has diminished. Nevertheless, such a system can mitigate a rear-end collision so that the impact speed is reduced. This example is described in Section 3.1. The second example considers the reaction time of the driver and how fast the driver can move the steering wheel. Including these features in the description of the driver, the possibility to steer away from a possible rear-end collision decreases compared to the case with immediate control actions. Hence, the active safety system can intervene with autonomous braking earlier which gives improved chances to avoid an accident, as well as larger reductions of impact speed. This example is described in Section 3.2. In the third example the risk of off-road accidents in curves due to too high speed is considered. The driver is described as a controller with the objective to follow the road. Using preview information about the road, and mathematical models of the vehicle and the driver, the driving ahead of the present position of the vehicle can be simulated. In this way it is possible to predict critical situations where the road friction does not suffice to give the tire forces to hold the vehicle on the road. This makes it possible to issue an early warning, or to automatically reduce the velocity in a gentle way, before the critical situation occurs. This is in contrast to, e.g. an ESP system which is activated once the loss of control is imminent. The advantage is that one potentially can avoid more accidents with a less intrusive intervention. This example is described in Section 3.3.

2. SYSTEM ARCHITECTURE

In Figure 1 an overview of a general active safety system is depicted. The simpler active safety functions only make use parts of the architecture. For example, for anti-lock brakes (ABS) and yaw-stability control systems (ESP) the “Treat Assessment”, “Decision Making” and the “Intervention Module” only use signals about the vehicle state giving information about if a wheel is about to slide. This means that no information about the driver or the environment is used.

More advanced systems such as lane departure warning systems, and rear-end collision mitigation by braking also make use of signals giving information about the vehicle surroundings, the “Environment Information” block in Figure 1 as input to the “Treat Assessment” and “Intervention Module”. Hence, such systems require sensors and signal processing delivering this information.

The next step, which is the focus of this paper, is the improvement which is possible to obtain by also considering the driver as a part of the system. This means that the threat assessment block contains a driver model, and that it can receive signals from the driver’s actions illustrated with the “Driver” block in Figure 1. With a driver model, in combination with information about the environment, it is possible to make predictions with larger horizon on which new active safety systems can be based. The potential of these systems are of course dependent on the quality of the driver models and the sensor systems.

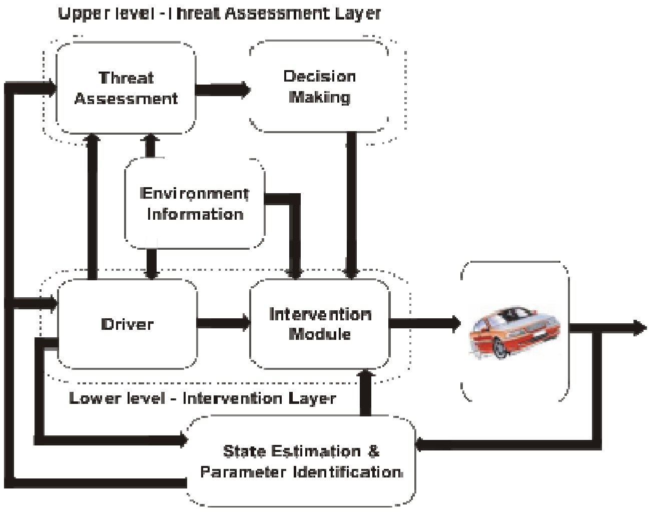

Figure 1. Possible general description of an active safety system. Simple threat assessment algorithms, like those for ABS and ESP, make use of information only about the vehicle state. Next step is to include information from the environment like in some lane keeping systems. More advanced algorithms also make use of information about the driver.

3. THREAT ASSESSMENT EXAMPLES

3.1 Threat Assessment without Driver Model

In its simplest form threat assessment does not take driver behaviour into account. The first generation Volvo's of Collision Warning with Auto Brake [*3*] is based on a threat assessment that makes use of velocity measurements and a constant acceleration model for the behaviour of the host and lead target vehicle. The motion of the host vehicle in relation to the lead target vehicles is analyzed and possible collision event is said to be imminent as soon as neither the maximum steering nor maximum brake action could lead to an avoidance of the rear-end collision. In terms of accelerations this means that as soon as the maximum achievable lateral and longitudinal acceleration due to steering and braking action is less than the needed respective accelerations, a collision is imminent. The ratio of the needed acceleration and maximum achievable acceleration for braking and steering actions are denoted as braking threat number (BTN) and steering threat number (STN), respectively, in the following way,

$$BTN = \frac{a_{x,needed}}{a_{x,available}} \text{ and } STN = \frac{a_{y,needed}}{a_{y,available}} \qquad (1)$$

In [*1*] BTN and STN are described as quantifiers for the collision risk. The available accelerations are dependent on the tire-to-road friction. When both BTN and STN are larger than 1 a collision is judged to be imminent, *i.e.* physically unavoidable, and automatic emergency braking is applied. As depicted in Figure 2, an accident cannot be avoided for velocities larger than 25km/h. For larger speeds the impact speed will however be reduced, and thus the consequences for the occupants [*4*].

Using this criterion gives a low risk for false interventions that could disturb the driver during normal driving, but the benefit of the system would improve drastically if the impact speed was reduced even more due to an earlier auto brake intervention.

One way of achieving this is to incorporate actuator dynamics. In the model above it is assumed that longitudinal and lateral acceleration can be achieved immediately. But due to actuator and vehicle dynamics this is not possible. Knowing that it takes time to build up this acceleration one could adapt the BTN and STN calculations, as suggested in [*1*]. This will lead to earlier intervention and thus increased benefit.

3.2 Threat Assessment with Simple Driver Model

Instead of starting an automatic intervention when it is *physically* impossible to avoid a collision, one could start automatic intervention when it is judged impossible for the *driver* to avoid a collision. Using the latter requires that one incorporates a driver model into the threat assessment model together with the velocity signals.

One relative simple way of doing this is by judging whether the driver is distracted. In [*5*] a situation assessment algorithm is proposed that estimates whether the driver of the host vehicle is *distracted* or not. The algorithm uses the fact that accident research shows that up to 93% of all drivers were distracted just before the rear-end collision occurred [*6*] suggesting that the driver did not steer due to the distraction.

The algorithm starts to classify the driver as either *active* or *passive*. In the second step, only passive drivers can be classified as distracted. The driver is classified as active when

- $|\omega| > 1$ rad/s

- or $|\omega| > 0.5$ rad/s continuously for at least 0.5s during the preceding 1.0s,

where ω is the steering wheel angle change rate. The rest of the time, the driver is assessed as passive. Secondly, the algorithm assesses possible threats from lead vehicles in terms of the STN. The driver is now assessed as distracted if

- STN exceeds 0.5
- and the driver is assessed as passive
- and the lead vehicle has a velocity below 10km/h.

The additional impact speed reduction that can be achieved when the driver is correctly assessed as distracted is depicted in Figure 2.

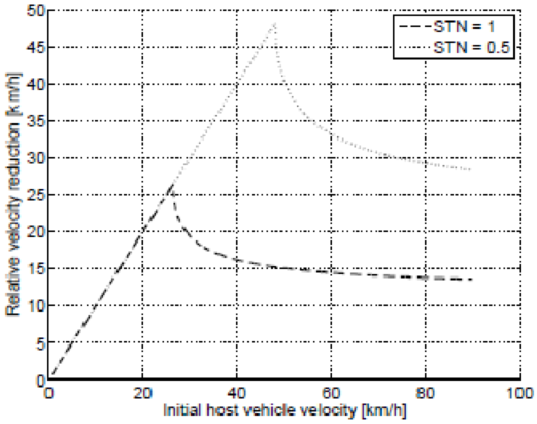

Figure 2. Relative velocity reduction for different host vehicle speeds when driving straight towards a stationary lead vehicle, showing that incorporating driver distraction (STN = 0.5) increases potential as compared with not incorporating this (STN = 1).

Additionally, performing earlier interventions when the driver is assessed as being distracted do not cause any additional false interventions as verified in a set of 200 driving hours in real traffic conditions. This illustrates how even a simple driver model can improve the benefit of an active safety feature.

Another example of a relative simple driver model is provided in [*7*]. A driver does not achieve maximum acceleration immediately when braking or steering a vehicle. So the potential avoidance manoeuvres are parameterized such that they represent common driver behaviour. One parameterization is presented for steering manoeuvres and another for braking or acceleration manoeuvres. Each type of manoeuvre is described using only one parameter, which is selected such that the severity of the manoeuvre increases with an increasing parameter value. The vehicle speed is assumed to be constant while the driver steers, $v = v_0$, and the curvature is assumed to be constant while the driver brakes or accelerates, c = c0.

1) Steering manoeuvres: During normal driving, drivers often use steering manoeuvres with a constant steering wheel angle rate followed by a constant steering wheel angle [*8*]. So a natural parameterization for steering manoeuvres is to hold the steering wheel angle rate constant during a limited time interval, until reaching a final steering wheel angle.

2) Similarly as for steering manoeuvres, the parameterization of potential braking and accelerating manoeuvres is selected as a constant jerk up to a maximum acceleration. This profile corresponds well to acceleration profiles for many brake actuators with a limited acceleration change rate and a limited deceleration capacity.

Dynamic effects of these manoeuvres were also included in the vehicle model, for example a delay in the steering.

The result of incorporating this approach for rear-end collisions is depicted in Figure 3. By including a model of the dynamics of the driver, a manoeuvre avoiding a collision needs to be initiated earlier. Hence, the automatic braking can intervene earlier which gives a larger velocity reduction.

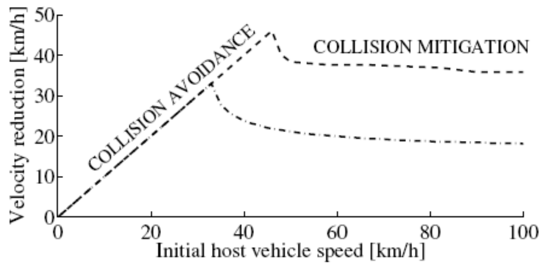

Figure 3. Velocity reduction versus host vehicle speeds when driving straight towards a stationary lead vehicle. The dash-dotted line shows the result using constant acceleration model (no driver model). The dashed line shows the performance when the driver model is included.

Also this algorithm was verified on a data set of 200 hours of driving without any false interventions. This again shows that incorporating knowledge about the driver, in combination with signals about the traffic situation, can increase the benefit of an active safety function without significantly increasing the risk for false interventions.

3.3 More Advanced Driver Model

The next step in the direction of more advanced driver models is to consider the dynamics of the closed loop system of driver and vehicle. With more advanced information system giving information about the curvature of the road ahead of the vehicle, the objective of the driver is to follow the road. In this context, the driver can be seen as the controller managing the vehicle to follow the road.

In this way an active safety function can be defined, based on vehicle dynamic models and driver models in connection with advanced sensing technologies providing information about road geometry, global position, velocity, and possibly, moving objects. This technique is introduced in [*9*] for a roadway departure prevention system and further developed in [*10*]. An illustration of this is shown in Figure 4 where the vehicle is approaching a curve and the algorithm calculates a prediction of the tire slip angles in the curve by simulating the closed-loop system of driver and vehicle using sensor information about position, velocity and road curvature as inputs signals.

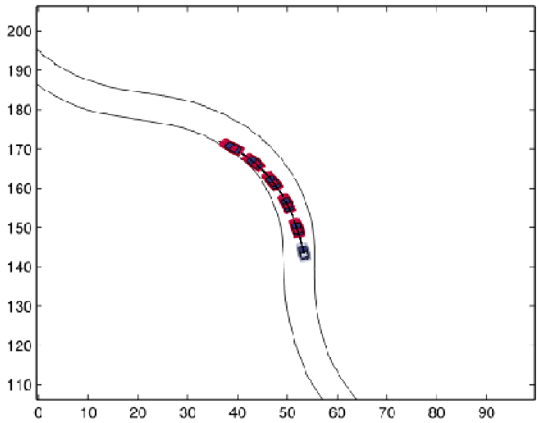

Figure 4. The vehicle is approaching a curve and the algorithm predicts the vehicle trajectory a time horizon ahead of the vehicle and calculates the necessary tire forces.

If the prediction indicates too large tire slip angles, a warning can be issued, or an intervention can be issued so that the velocity is decreased. Since this can be done slightly before the critical situation, a less intrusive action may suffice compared to what an ESP system would need issue.

The driver model used for the steering in [*9*] is described by

$$\delta = K_y e_y + K_\psi e_\psi(t_{prev}) \tag{2}$$

where δ is the steering angle which depends on the signals e_y, the vehicle's lateral displacement from the road at a distance *ds* ahead of the vehicle's centre of gravity, and e_ψ, the difference the vehicle's heading angle and the road's heading angle at the preview point which is t_{prev} seconds ahead of the vehicle. Figure 5 illustrates the driver model signals.

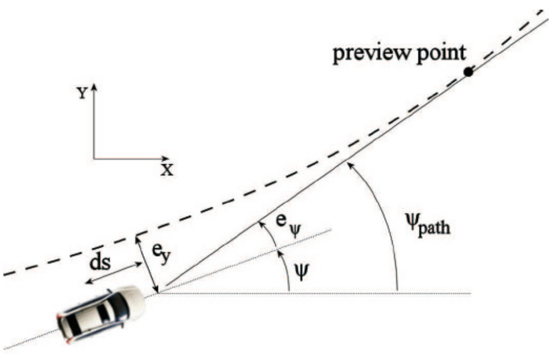

Figure 5. Illustration of the measures used in the driver model (2).

The parameters in the driver model K_y, K_ψ, and t_{prev} are estimated using measurements. See Figure 6.

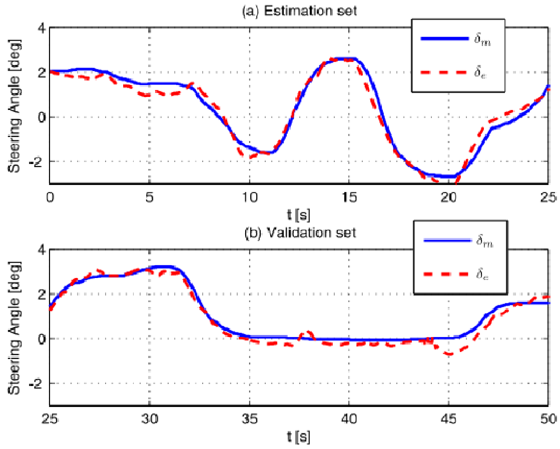

Figure 6. Measured steering angle together with the steering angle given by the model (5). A) Estimation data, B) Validation data.

It is a simple driver model. The first term gives a feedback contribution if the vehicle has an offset in the lane and the second term is a feed-forward contribution which depends on the curvature ahead of the vehicle.

Using data from a test drive, the proposed algorithm is validated against the existing ESP. The result is depicted in Figure 7. It shows the predicted tire slip angle together with an indicating function showing when the ESP system activates. From the figure it is clear that the algorithm indicates large slip angles approximately 1-2 seconds before the ESP system actually activates.

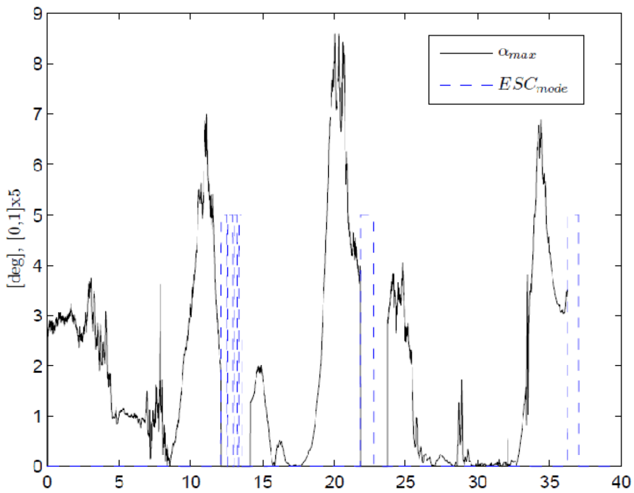

Figure 7. Solid: predicted tire slip angle, dashed: function indicating when the ESP system is activated. High slip angles is a clear indicator of imminent critical situation.

Hence, this time window has become available thanks to the proposed algorithm and it can be used for providing an earlier warning or intervention in order to minimize driver disturbance. Or, it can be used to start interventions earlier in order to increase the safety benefit.

For under-steered vehicles the preview of an imminent loss of control with an activation of the ESP system can be significant for avoiding a loss of control. The reason for this is that the vehicle's vertical load distribution in a curve reduces the normal force at that specific wheel where the ESP system needs to brake to stabilize the vehicle. Hence, the ESP system might have lost most of its power to stabilize the vehicle. This is illustrated in Figure 8 and further described in [*11*].

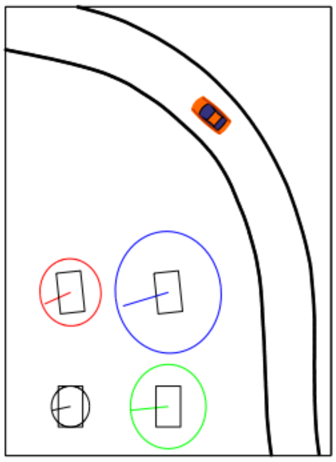

Figure 8. Illustration of a vehicle's vertical load distribution in a curve situation. The ellipses represent available friction at each wheel, the sizes of the ellipses depend on the vertical load and the forces produced at the tires are constrained to lie within the ellipses. In a curve situation, much of the vehicle's weight is redistributed to the outer side. As can be seen available brake force at the inner back wheel is greatly reduced.

4. DISCUSSION AND CONCLUSIONS

Using three examples it has been shown that knowledge on driver behaviour can be used to enhance active safety functionality. Together with sensor systems giving information about the traffic situation, a driver model makes it possible to make predictions about a traffic situation over a longer time horizon. This can be used for providing earlier and more comfortable interventions or for increasing the safety benefit, without significantly increasing the risk of false or unnecessary interventions.

The key for achieving this potential benefit is an accurate driver model. Typical challenges in obtaining a driver model are:

- Understanding driver behaviour in near-critical situations.
- Dealing with driver variability, as driver behaviour changes over time and varies between individuals.
- Obtaining on-line data on driver behaviour. This cannot be measured directly and has to be estimated from e.g. vehicle behaviour and driver inputs trough pedals and steering wheel.

These are topics for future research and the result will influence our daily life in traffic.

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