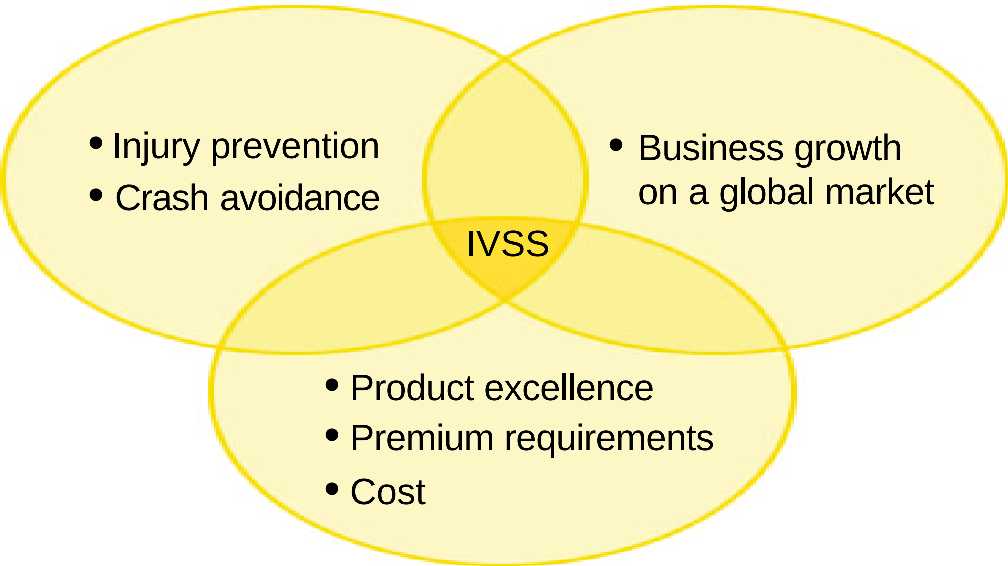
Systems for Collision Avoidance in Road Vehicles

Final IVSS Project Report

The IVSS Programme

The IVSS programme was set up to stimulate research and development for the road safety of the future. The end result will probably be new, smart technologies and new IT systems that will help reduce the number of traffic-related fatalities and serious injuries.

IVSS projects shall meet the following three criteria: road safety, economic growth and commercially marketable technical systems.



Three interacting components - for better safety, growth and competitiveness:

The human being

Preventive solutions based on the vehicle's most important component.

The road

Intelligent systems designed to increase security for all road users.

The vehicle

Active safety through pro-active technology.

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1. Introduction

Collision Avoidance systems, as a subsequent step to collision mitigation, are one of the great challenges in the area of active safety for road vehicles. Collision mitigation functions usually intervene when a collision is unavoidable, and actuate e.g. the brake system in order to reduce the consequences of a collision by reducing the impact speed. For collision mitigation functions it is generally true that the safety benefit becomes larger when the impact speed reduction is larger. The mitigational effect is here achieved by reducing the amount of collision energy by reducing the collision speed. The fundamental mechanism for collision avoidance is, however, different, as here the trajectory of the involved vehicle(s) is changed in way to avoid an impact. Principally, this can be done in two separate ways, which are addressed within the two subprojects Collision Mitigation by Braking (CMbB) and Collision Avoidance by Steering (CAbS). For Collision Mitigation Systems a special situation has been identified where Collision Avoidance potential exist, when the motion of surrounding traffic is studied and taken into account in the decision making. In that manner, CMbB will judge a threat situation even from an "escape path" point of view an thereby exhibits collision avoidance potential.

2. Subproject 1: Collision Mitigation by Braking

This section provides an overview of the main deliverables for the CMbB function and how they relate to the goals of the IVSS project. Furthermore, references to detailed descriptions and deliverables are given for each project activity. Note that some of the references are confidential Ford motor company (FMC) internal documents, e.g. invention disclosures etc.

2.1. Project overview

The CAS – CMbB project directly addresses all three main objectives (Traffic safety, Global growth, competitiveness). The main objective has been to develop methods for determining when and collision becomes unavoidable. Once it has been established that a collision is unavoidable, autonomous emergency braking is activated to reduce the collision speed. It is well known that distraction is one of the main causes to traffic accidents, see for instance Ref[3,4]. Therefore, collision mitigation systems are now being introduced to alleviate the problem. These system all consider the closest in-path object, where the in-path criteria is based on the assumption that the host vehicle continuous to travel with nearly unchanged yaw rate, a and determine when collision with this object is unavoidable. Because steering away from the danger is often a more effective way to avoid a collision, i.e. a change in host vehicle trajectory, these systems will often not be able to completely avoid a collisio n, without risking false braking interventions. However, by considering the entire traffic situation i.e. all objects in the vicinity of the own vehicle, the collision unavoidable state can be established earlier. This typically applies to e.g. crowded city traffic and also highway pile-ups. The objective of this project has been to develop methods to asses the collision threat in complex traffic environment with multiple objects. The result is a CMbB system, in the remainder called multiple-object CMbB, which in many scenarios can reduce the collision speed to zero, i.e. collision avoidance, instead of just mitigating the accident. Algorithms and evaluation is presented in Ref. [1,3,4].

Much effort has been spent on implementing the multiple-object CMbB function and test it in demonstrator vehicle. Within this work three generations of demonstrator vehicles have been built. The third generation demonstrator was demonstrated internally to management across different brands within FMC and to a large number of motor journalists at the Michelin Challenge Bibendum.
The multiple-object CMbB function is currently a development project at Volvo Cars R&D department. The purpose of the system is to increase base CMbB performance and thereby increasing safety for all road users and also to establish Volvo Car Corporation as a leader in the active safety field.

2.2. Connection to IVSS focus areas

The CMbB system most directly relate to the IVSS focus areas

- Driver degraded performance – A driver that can not perform properly will get assistance by the vehicle in reducing the collision speed which is provided by the pre-crash braking.
- Crashsafety & biomechanichs/"Just before the unavoidable" – The speed reduction caused by the autonomous braking will significantly reduce the crash violence. Current CMbB system can ideally reduce the collision speed by no more 25 km/h. The multiple object CMbB system may reduce the collision speed to zero. Note, that the speed reduction of any CMbB system will vary with the traffic scenario, and there will always exist situation where no speed reduction can be achieved.

2.3. Conclusions

The CAS – CMbB project has focus on how CMbB system shall perform in complex driving situations with multiple objects present. Algorithms which can provide full collision avoidance by braking for certain situations. Several demonstrator vehicle have been built in which a CMbB function with multiple target capacity is implemented. It has been decided to include this function in future Volvo CMS systems.

2.4. Referenser

[1]. R. Collin, Nu kan bilen bromsa själv, Aftonbladet, 2006-06-11.

[2]. http://www.challengebibendum.com/

[3]. 100- car naturalistic driving study..

[4]. Indiana-tri-level study…

2.5. Publications

[1]. J. Jansson, Collision Avoidance Theory with Application to Automotive Collision Mitigation

[2]. Active Safety Demonstration 2006 – VCC internal, Booklet in A5.

[3]. J. Jansson och F. Gustafsson, Multiple Object Collision Avoidance Decision Making, Submitted to IEEE Transactions on Control Systems Technology – Special issue on automotive control, 2006.

[4]. J. Jansson och F. Gustafsson, A framework and automotive application of collision avoidance decision making, Submitted to International Federation of Automatic Control Journal: Automatica, 2006.

[5]. J. Jansson and M. Brännström, Threat Assessment for Unexpected Events, ANAQUA ID: 81152228, Status: draft.

[6]. J. Jansson M. Brännström, Intersection Collision Avoidance Method, ANAQUA ID: 81137971, Status: To be filed.

[7]. R. Trombley, J. Jansson, Steerable Path Assessment, ANAQUA ID: 81136481, Status: Closed.

[8]. R. Trombley, J. Jansson, Crossing Target Threat Assessment, ANAQUA ID: 81134700, Status: Closed.

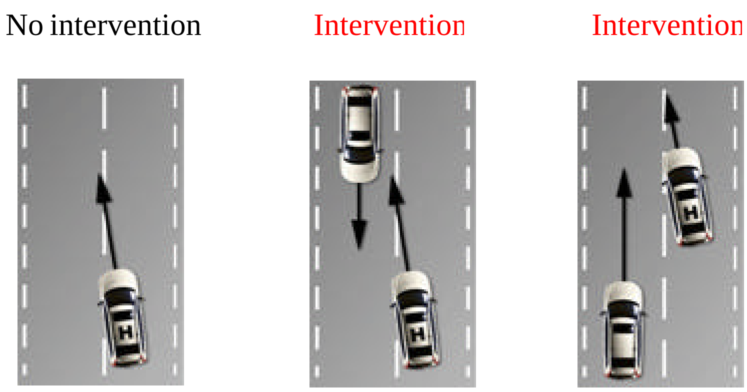
[9]. M. Brännström, J. Jansson et al., Multiple Collision Mitigation System, ANAQUA ID: 81128798, Status: Filed.

3. Subproject 2: Collision Avoidance by Steering

3.1. Project overview

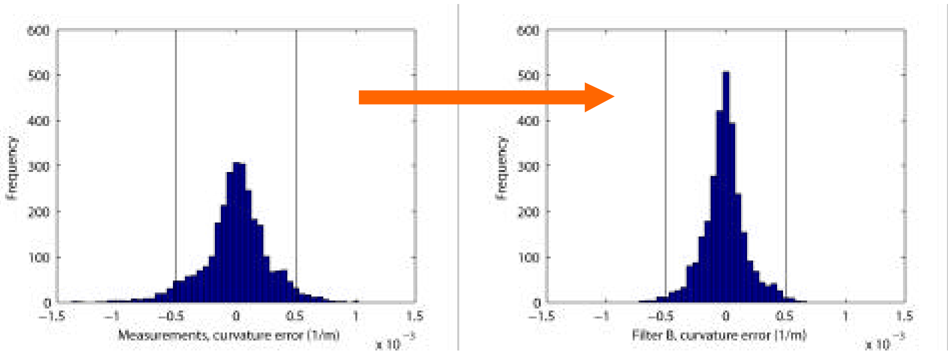
A central theme in the subproject "Collision Avoidance by Steering" has been the active safety function Emergency Lane Assist (ELA) which is a new type of lane guidance system. Different types of lane guidance systems have recently been presented by several car manufacturers. Lane guidance systems try to prevent lane departure and the motivation is that many accidents occur due to a distracted or drowsy driver departing from a lane and colliding with a road-side object or an oncoming vehicle. Today, there are two major problems with such technology. The first is false alarms when crossing the lane markings intentionally. The second is misuse. A system that uses a steering wheel to prevent lane departure could be used as an autopilot by the driver while carrying out distractive tasks.

Emergency Lane Assist (ELA) provides an alternative when it comes to reducing false alarms and misuse problems associated with conventional lane guidance systems. This is achieved by only trying to prevent *dangerous* lane departure. The system monitors adjacent lanes and as long as there are no other vehicles approaching, the lane markings can be crossed without ELA intervention, but as soon as a commenced lane change manoeuvre is considered dangerous, for example with respect to an oncoming vehicle, a torque is applied to the steering wheel in order to prevent lane departure. The risk level of a lane change manoeuvre is assessed based on the position and motion of vehicles in the adjacent lanes. In addition, road edges, barriers or even solid lane markings could also be used to activate intervention. This approach makes ELA a pure safety system rather than a comfort/convenience system. Below, critical ELA situations are shown:

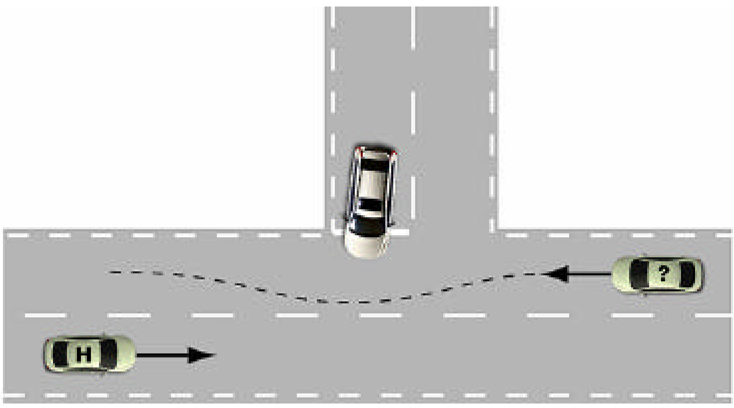


ELA detects lane departure manoeuvres that are likely to result in a collision and prevents them by applying a steering wheel torque.

The ELA function puts tough requirements on the accuracy of the information from the sensors, in particular the road shape and the position of surrounding objects. Several signal processing methods have been developed and evaluated in order to improve the accuracy of the sensor information, and these improvements are also analysed in how they relate to the ELA requirements. This image shows how the error in the curvature estimate signal has been reduced using a centralised, model based Kalman filter. The vertical line represents a tolerance level that ELA puts on the signal. It can be seen that the amount of time that the error is above the tolerance is greatly reduced.



Furthermore, a novel, statistical threat assessment algorithm has been developed which analyzes interactions between all objects in the road scene. For instance, the following scenario poses a threat to the host vehicle H since the oncoming vehicle most likely will have to swerve to avoid the vehicle in the intersection.



Since the method is based on a statistical model, it can consider many possible future hypothesis. This is a strength compared to methods based on a single, deterministic prediction.

The ELA safety function has been evaluated on a large data set, recorded during typical driving situations, was used. The entire database consists of 40 000 km of data, so far the system has been tested on a subset of 2 000 km, chosen such that a representative variety of driving conditions are kept. If situations with extremely poor or ambiguous lane markings, which can be detected, is disregard, we have so far not experienced any false alarms, which is an encouraging result.

The system has been tested on a variety of roads and weather conditions in order to emulate typical driving situations.

3.2. Connection to IVSS focus areas

The subproject CAbS has contributed to the main goals of IVSS. The contribution to safety is clear since a the research is about active safety systems, which aims at reducing the total number of accidents. The presented safety function ELA is currently a development project at Volvo Cars R&D department. The presented techniques, the signal processing and threat assessment methods, are developed mainly for the ELA function, but are general and could contribute to other active safety functions as well. It contributes to the competitiveness of Volvo Car Corporation and Ford Motor Company by providing new safety features for their customers. This is an extremely important and expansive area, particularly important for Volvo who has a safety marketing profile.

It also contributes to at least two of the IVSS focus areas. The main purpose of the ELA safety function is to prevent unintentional lane departure manoeuvres. The main reason for drivers to unintentionally depart from the lane is distraction or drowsiness, i.e., reduced driver capability. Since the function is designed to give a steering intervention just before the vehicles enters the collision unavoidable zone, it also belongs to the focus area "Just before the unavoidable".

3.3. Publications

[1]. Eidehall, A., Pohl, J., Gustafsson, F. and Ekmark, J. “A new approach to lane guidance systems”. In Proceedings of the IEEE Intelligent Transportation Systems 2005, pages 108-112, Vienna, Austria. This is the first presentation of the ELA safety function.

[2]. Eidehall, A. “Lane game”. In Traffic Technology International 2005 Annual Review, pages 40-42. This is a popular science version of P1.

[3]. Eidehall, A., Pohl, J., Gustafsson, F. and Ekmark, J. “Towards autonomous collision avoidance by steering”. Accepted for publication in IEEE Transactions on Intelligent Transportation Systems, 2006. This is an extended version of P1 which also includes the development of the ELA concept based on accident statistics.

[4]. Eidehall, A. and Gustafsson, F. “Combined road prediction and target tracking in collision avoidance”. In Proceedings of the IEEE Intelligent Vehicles Symposium 2004, pages 619-624, Parma, Italy. This is the first implementation of the integrated filter for road shape and object tracking.

[5]. Eidehall, A., Pohl, J. and Gustafsson, F. “Joint road geometry estimation and vehicle tracking”. Provisionally accepted for publication in Control Engineering Practice, 2006. This is an extended version of P4 which is a more mature implementation and also includes a more thorough analysis of the performance.

[6]. Schön, T. B., Eidehall, A. and Gustafsson, F. “Lane Departure Detection for Improved Road Geometry Estimation”. In Proceedings of the IEEE Intelligent Vehicles Symposium 2006, pages 546-551, Tokyo, Japan. This paper shows how a Kalman filter model can be adapted online according to changes in the behaviour of the tracked vehicles.

[7]. Eidehall, A. and Petersson, L. “Threat assessment of general road scenes using Monte Carlo sampling”. In Proceedings of the IEEE Intelligent Transportation Systems 2006, pages 1173-1178, Toronto, Canada. This is a threat assessment algorithm for long term predictions based on stochastic driver models.

[8]. Eidehall, A. and Petersson, L. “Statistical threat assessment of general road scenes using Monte Carlo sampling”. Submitted to IEEE Transactions on Intelligent Transportation Systems, 2006. This is an extended version of P7 which also includes evaluation on authentic sensor data.

[9]. Eidehall, A., Schön, T. B. and Gustafsson F. “The Marginalised Particle Filter for Automotive Tracking Applications”. In Proceedings of the IEEE Intelligent Vehicles Symposium 2005, pages 369-374, Las Vegas, USA. This shows how the marginalized particle filter can be used in the combined road shape/object tracking filter.

[10]. Eidehall, A. and Gustafsson, F. “Obtaining reference road geometry parameters from recorded sensor data”. In Proceedings of the IEEE Intelligent Vehicles Symposium 2006, pages 256-260, Tokyo, Japan. This paper presents a method to obtain ground truth data that can be used for filter tuning.

4. Outlook and future work

While the two presented subprojects do make a substantial contribution to the body of actives safety research, the question of remaining research fields arises. Future research that adds on to the findings from this project can be divided into three areas:

- High-level integration of CMbB and CAbS
  For the ELA function the time horizon between start of intervention and predicted time to collision is crucial in order to alter the host vehicles trajectory to avoid the predicted collision. The longer this time horizon is, the more sensitive is the prediction of a collision, and thereby the planned escape trajectory, towards changes in the environment. The ELA function must therefore contain a module that monitors the likelihood for a successful intervention, even **after** an intervention has been started. If a commenced intervention is judged to have a low potential for success, the host vehicle could presumably start to brake in order to prolong time-to-collision. However, this approach requires a more general approach to threat assessment as it has been done in this project. Research would even include a safety benefit estimation of the proposed system.

- Driver Distraction and Drowsiness Detection integration with CAbS
  Active safety research has shown that many traffic accidents occur due to inadequate driver behavior. For active safety function such as CAbS functionality the state of the driver is unknown. Such kinds of functions can benefit from driver state information, as intervention thresholds can be adapted accordingly, leading to a higher collision avoidance potential. Research in this field would focus on integration aspects of these functions, the relationship between driver reaction time and detected visual focus as well as on reliability aspects of driver monitoring systems.

- CAbS integration with infrastructure or surrounding vehicle based information sources
  Shortcomings of current CAbS functionality is, as pointed out, mainly due to uncertainty about environmental conditions, which is mainly the available tire to road fiction. If the friction level would be known throughout the intervention horizon, the CAbS function can be adjusted accordingly resulting in an optimal trade off between unwanted interventions and true positive performance. Even uncertainty in environmental sensing technologies that deliver required information such as longitudinal and lateral information on surrounding targets as well as their corresponding derivatives range, range rate, range acceleration are a limiting factor of system performance. These two areas can be addressed with infrastructure or inter-vehicle communication. From a function perspective it must be kept in mind that emphasis should be put on **what** should be transmitted , and not **how**, that is what information is required with which fidelity, and that how

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