FFI

Systems for Roadway Departure Avoidance

Project within FFI- Vehicle and Traffic Safety

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Content

 FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**
For more information: www.vinnova.se/ffi

1. Executive summary

The main goal of this research project was to extend existing research and development in the field of lane keeping assistance. The ambitions were two folded. First, it was desired to try dealing with roadway departure avoidance systems without using information about lane markings. I.e. to rely on other road geometry information such as road edge or barriers. Secondly, the project aimed to open up the field of autonomous steering interventions to more evasive scenarios. Until today, only very conservative steering intervention systems have found its way to the market.

Here follows a resume of activities and results from the project since the start of the project.

2007
The project was initiated with a literature study on current state of the art in parallel with a study of accident statistics. The purpose of evaluating accident statistics was to gain insight in the causes of roadway departures and to point out the most common pre-crash scenarios.

2008
Loosing control in a curve showed to be a common pre-crash scenario so we decided to begin considering this type of accidents. Initially, we studied fundamental vehicle dynamics. In particular a study was conducted in which vehicle models with varying level of modelled dynamics were compared. The study was summarized in a paper that was presented at Reglermötet. The paper was later extended and sent to 21st International Conference on Enhanced Safety of Vehicles.

We further developed a method that based on measurements of the vehicle state and information about the road ahead of the vehicle, evaluates whether a vehicle can stay on the road while maintaining vehicle stability. A roadway departure prevention system can use this method as a base for issuing interventions that assist the driver. The efforts have resulted in a patent application and the method was presented at the IEEE Intelligent Vehicle Symposium (2009).

2009
We considered a complete system, consisting of an upper level threat assessment layer and a lower level intervention layer. The lower level intervention controller was implemented using model predictive control approaches and the complete system was evaluated with both experimental and simulation results. The work was presented at 21st International Symposium on Dynamics of Vehicles on Roads and Tracks, August 2009. Since mid year 2009, work to develop a general framework for threat assessment has been conducted in cooperation with a co-researcher at Chalmers. In parallel, work on methods for sensitivity analysis of active safety systems, has been carried out.

2010
During winter and beginning of spring 2010, much focus was put on writing a thesis for the degree of licentiate of engineering. The licentiate thesis was successfully defended by Mohammad Ali on 19th of May.

2011
During the end of 2010 and beginning of 2011 the previously developed algorithms were implemented to run in real-time in a prototype vehicle. Experiments on a frozen lake in the north of Sweden were conducted in March 2011. A journal paper presenting the acquired results has been written and submitted to IEEE Transactions on Intelligent Transportation Systems.

We have also investigated (i) how the reachability based threat assessment methods can be extended to account for nonlinear system dynamics and possibly nonlinear, non-convex constraints and (ii) how the reachability based threat assessment methods can be adjusted to account for uncertainties in the model parameters, state estimates and estimates of exogenous disturbance signals.

The problem (i) has been tackled using interval arithmetic which is commonly used in e.g. the fault detection field. A preliminary study was presented at the IFAC World Congress. Experimental results have by now been compiled and a journal paper in which we present the proposed approach is currently being written.

The problem (ii) has also been tackled. The case where model parameter uncertainties is accounted for is particularly challenging since it results in a non-convex problem. The developed algorithms for dealing with model parameters were presented at the combined IEEE Conference on Decision and Control and European Control Conference. In addition, a journal paper in which we deal with uncertainties in model parameters, state estimates and estimates of exogenous disturbance signals was also written.

2012
In March and April, Mohammad Ali visited UC Berkeley as a visiting researcher. Based on previous results from this project, an MPC-controller has been developed that deals with both threat assessment and control simultaneously. This means that only one optimization problem needs to be solved for both determining whether the driver needs assistance and how to assist the driver. This also eliminates the need for switching logics between manual and assisted modes.

In addition, the MPC-controller has been modified to also account for stationary roadside obstacles. A transformation of the system dynamics was introduced which enables writing the obstacle avoidance constraints in a simple way.

The work in this project was summarised in Mohammad Ali´s PhD thesis which was successfully defended September 21st. A list of publications and summary of

contributions can be found in the thesis. The thesis could be downloaded from:
http://publications.lib.chalmers.se/records/fulltext/162548.pdf

2. Background

While the transportation capabilities enabled by road traffic have provided invaluable social and economic benefits, they are also associated with negative consequences. Today more than ever, huge research and development efforts are invested in reducing negative effects like traffic fatalities, gas emissions and traffic congestions. However, at the very core of these efforts is the problem of maintaining an acceptable transportation performance. This is the challenge. In this project, this challenge is addressed with respect to automotive safety. In particular, we focus on the problem of preventing roadway departure accidents through automated safety interventions without degrading vehicle performance by excessive interventions, since such degradation is difficult to gain acceptance for.

3. Objective

Volvo Car Corporation shall be the world leading car manufacturer within automotive safety. This requires that Volvo shall offer world-first active safety systems, which significantly reduce the risk of collisions. Effective roadway departure avoidance functions are therefore a necessity to reach that goal.

4. Results and deliverables

4.1 Delivery to FFI-goals

The FFI program has the overall goal to contribute to the development of vehicles with an optimal combination of active and passive systems that reduces the number of accidents and the consequences thereof.

In light of the above, this project results are very much contributing to the fulfilment of the goals. The results are mainly applicable to vehicles, but there is no limitation to passenger cars.

This work has focused on the problem of improving vehicle safety while maintaining an acceptable vehicle performance. Methods to assess accident threats, determine interventions and control vehicle motion have been developed to improve vehicle safety. In order to avoid degrading vehicle performance through large safety margins, the

developed methods have been designed such that interventions can be deployed only when it can be assured that the situation is critical. The following have been considered:

1. A novel safety function that utilizes road preview information to avoid vehicle control loss has been proposed.

2. Threat assessment algorithms have been developed. The algorithms utilize vehicle and mathematical driver models to properly account for limitations in the vehicle's and the driver's capabilities.

3. An algorithm for online estimation of a driver model has been implemented. The driver modelling is used as an integrated part of the threat assessment algorithms.

4. The threat assessment has been extended to account for uncertainties in the state and disturbance estimates as well as system parameters like the driver model parameters.

5. The threat assessment methods have been modified to account for nonlinear system dynamics. Moreover, nonlinear dynamics are included while maintaining theoretical guarantees that false threat detections are avoided.

6. A novel framework for decision making in general automotive accident avoidance systems has been developed. The framework enables the integration of a wide range of control strategies ranging from completely autonomous coordination of braking and steering to previously developed control schemes implemented in e.g. onboard yaw control systems.

7. Intervention/control strategies for automated coordination of both steering and braking have been implemented and evaluated.

8. All the methods presented in the work have been experimentally validated.

5. Dissemination and publications

5.1 Knowledge and results dissemination

Within the area of active safety, there is a clear trend towards more focus on performance evaluation of active safety systems. Both from institutes, but also from automotive press and other associations. For a brand like Volvo, it is of utmost importance that the outcome of field test is of advantage. Consequently, this trend will have impacts on the speed and direction of development.

5.2 Publications

2012
M. Ali, P. Falcone and J. Sjöberg, Threat Assessment Design under Driver Parameter Uncertainty, IEEE Conference on Decision and Control, December 2012, Maui, USA.

A. Gray, M. Ali, Y. Gao, K. Hedrick, F. Borrelli, Semi-Autonomous Vehicle Control for Roadway Departure and Obstacle Avoidance, IFAC Symposium on Control in Transportation Systems, September 2012, Sofia, Bulgaria.

A. Gray, M. Ali, Y. Gao, K. Hedrick, F. Borrelli, Integrated Threat Assessment and Control Design for Roadway Departure Avoidance, IEEE Intelligent Transportation Systems Conference, September 2012, Anchorage, USA.

2011
Ali, Mohammad; Falcone, Paolo; Sjöberg, Jonas (2011)
Model-Based Threat Assessment for Lane Guidance Systems. American Control Conference, San Francisco, CA, USA, June 29-July 01, 2011.

Ali, Mohammad; Falcone, Paolo; Sjöberg, Jonas (2011)
Model-Based Threat Assessment in Semi-Autonomous Vehicles with Model Parameter Uncertainties. 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, December 12-15, 2011.

Ali, Mohammad; Olsson, Claes; Sjöberg, Jonas (2011)
Real-time Implementation of a Novel Safety Function for Prevention of Loss of Vehicle Control. IEEE Intelligent Transportation Systems Conference 2011.

Falcone, Paolo; Ali, Mohammad; Sjöberg, Jonas (2011)
Predictive Threat Assessment via Reachability Analysis and Set Invariance Theory. IEEE Transactions on Intelligent Transportation Systems,

Gelso, Esteban R.; Ali, Mohammad; Sjöberg, Jonas (2011)
Threat assessment for driver assistance systems using interval-based techniques. 18th IFAC World Congress.

2010
Ali, Mohammad (2010)
On Automotive Roadway Departure Prevention. Lic Thesis: Chalmers University of Technology.

Falcone, Paolo; Ali, Mohammad; Sjöberg, Jonas (2010)
Set-Based Threat Assessment in Semi-Autonomous Vehicles. IFAC Symposium Advances in Automotive Control, Munich, Germany, 12 - 14 July 2010.

Nilsson, Jonas; Ali, Mohammad
Sensitivity Analysis and Tuning for Active Safety Systems. IEEE Intelligent
Transportation Systems Conference. s. 161-167. ISBN 978-1-4244-7657-2 ISSN 2153-
0009

Sjöberg, Jonas; Coelingh, Erik; Ali, Mohammad; Brännström, Mattias; Falcone, Paolo
(2010)
Driver Models to Increase the Potential of Automotive Active Safety Functions.
Proceedings of 18th European Signal Processing Conference 2010, Aalborg, Denmark,
August 23-27 2010.

2009
Ali, Mohammad; Sjöberg, Jonas (2009)
Impact of Different Vehicle Models on Threat Assessment in Critical Curve Situations.
21st International Conference on Enhanced Safety of Vehicles.

Ali, Mohammad; Olsson, Claes; Sjöberg, Jonas (2009)
Towards Predictive Yaw Stability Control. IV´09 - 2009 IEEE Intelligent Vehicles
Symposium.

Ali, Mohammad; Falcone, Paolo; Sjöberg, Jonas (2009)
A Predictive Approach to Roadway Departure Prevention. 21st IAVSD Symposium on
Dynamics of Vehicles on Roads and Tracks, Stockholm, 17-21 August 2009.

6. Conclusions and future research

Further development of the roadway departure prevention applications towards
industrialization is one possible direction for future work. This involves modifications of
code for real-time execution and extensive testing of the algorithms' performance in real
world scenarios.

Another direction is to further improve performance and extend the scope of the
developed threat assessment methods. This can be achieved by modifying the models that
have been used to account for a wider range of scenarios. Some example scenarios to
which the scope might be extended are presented in Figure 1.

Extending the scope can be performed by utilizing the methods that have been proposed
in this thesis and adjusting the modelling to account for a wider range of accident
scenarios. In this regard, the modelling of drivers' behaviour is particularly challenging.
The driver model considered in this work provides reliable predictions on e.g. highways
or country roads, when there are no other vehicles involved. It does not take into account

e.g. interaction with preceding vehicles, speed adjustment in curves or more complex behaviour in e.g. traffic intersections. Further modelling and estimation of driver behaviour to account for, in particular, drivers' longitudinal behaviour would be valuable, both for increasing performance in the roadway departure scenarios considered in the PhD thesis and also for extending the scope to more general situations
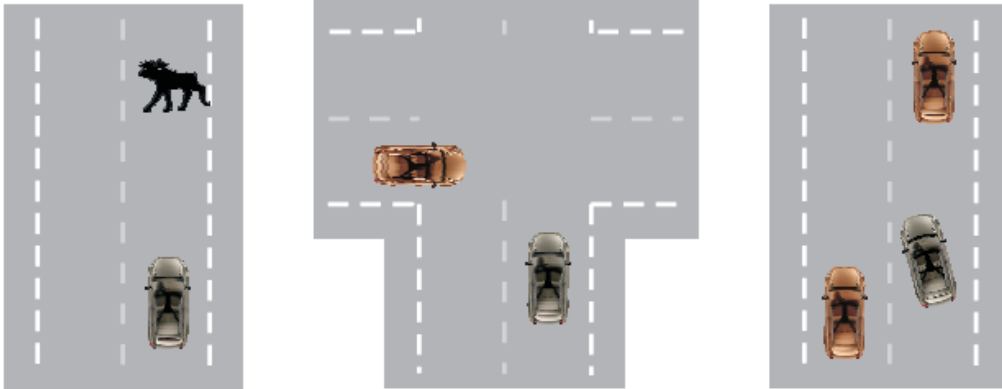

Figure 1: Examples of traffic scenarios that might lead to accident

7. Participating parties and contact person

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