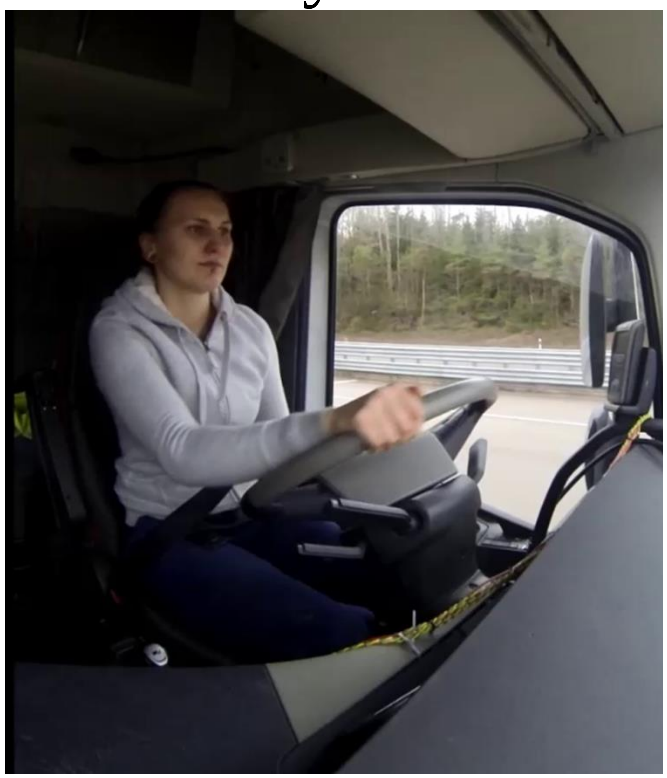
Active Steering Force Feedback for Commercial Heavy Vehicles



Project within: Fordons- och trafiksäkerhet

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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

In order to meet the traffic safety goals that were set up by Swedish government of 50 % less fatalities and 25 % less severely injured by 2020 due to traffic accidents the aim here in this project was to strive for safe commercial heavy vehicles. The observed majority of fatal and severe injury accidents with commercial heavy vehicles involved were identified as head on collisions with a light vehicle coming into the wrong lane. Thus, systems like Electronic Stability Control and Lane Keeping Support for commercial heavy vehicles were assumed to have only a very small impact on reducing the main cause of fatalities and severely injured for crashes where commercial heavy vehicle are involved. Instead it was foreseen by the Swedish Road Administration that one main ‘indicator’ for future safe commercial heavy vehicles was automated emergency braking systems. Therefore, in this project the focus was on automated emergency braking systems for commercial heavy vehicles and how active steering force feedback could be designed to guide the driver to maintain the heavy vehicle combination within its lane until full stop has been reached.

When starting the project a hypothesis was stated suggesting “that stability envelopes for commercial heavy vehicle combinations on under-, over steering, roll over, jack-knife, and swing out can be informed by steering force feedback to the driver.” To be able to test this idea fundamental functionality was developed, including vehicle combination envelope characterisation, force feedback design, and an architectural design for combined steering and braking. This was followed by several test-track experiments; conducted to understand human behaviour both in a generic way as well as that in specific use cases.

The suggested hypothesis turned out partly accepted and partly rejected. Humans respond very differently to force feedback depending on the amount of time available to process the information. This means that force feedback can be very effective in representing slow events, such as over-steer. But in the case of a rapid event, where the time from stimuli to response has to be short, force feedback is not as effective. The underlying reason for this lies in the human neural system, and whether the stimuli activate reflex or more conscious actions. In rapid events it would therefore be necessary to support the driver, not only by providing force feedback, but also to use other actuators to affect the motion of the vehicle, until the point where the driver acts deliberately.

The conducted work has led to: ten publications, whereof two master thesis and one licentiate thesis; one patent application; core functionality and knowledge made available to all project partners; and valuable input when setting up a new project (AFFECT step 2) that will continue to investigate how oncoming accidents involving heavy vehicles can be prevented.

2. Background

Here follows a short version of the background for the project. For a longer version see [11].

Accident studies on commercial heavy vehicles performed in U.S.A. by the National Highway Traffic Safety Administration (NHTSA) showed for year 2009 that of the fatalities, 75 % were occupants of another vehicle, 15 % were commercial heavy vehicle occupants, the remaining 10 % were non-occupants such as pedestrians and bicyclists [12]. The accident characteristics showed that in half of the fatal two-vehicle accidents both vehicles were driving straight, in 30 % of these accidents it was a frontal collision [12]. This is in line with the analysis done in [13] about the most common cause for fatalities and injured involving commercial heavy vehicles also in Sweden, namely frontal collision. This gives traffic safety researchers for commercial heavy vehicles a clear target of what use cases that are of relevance to reduce the number of fatalities by 2020.

The use case of maintaining trajectory while emergency braking the commercial heavy vehicle is one of the main use cases according to [12]-[13]. Maintaining the desired trajectory during emergency braking was therefore analysed deeply in this project, i.e. keeping the truck in its intended lane in presence of disturbances such as unbalanced road friction, failure of trailer Anti-lock Braking System (ABS), or even front axle steering damaged due to a collision with a light vehicle. This was not designed prior to the project.

A commercial heavy vehicle can be associated with a certain stability envelope. This means a combination of road conditions, vehicle states, and also associated driver limitations that can guarantee a safe outcome. As emergency braking under severe situations can cause large disturbances on the vehicle there is a risk that the stability envelope is violated, which may lead to a severe accident. It is therefore of outermost importance when assisting the driver to both estimate where in the stability envelope that the vehicle currently is and also to maintain the vehicle in this envelope by controlling the motion. The exact type of control that can be exerted on the vehicle combination is limited by the set of actuators at hand. In practise this makes the step of controlling the motion of the vehicle non-trivial.

3. Objective

The overall objective of the project was to build up knowledge and develop functionality for handling the situation of emergency braking when disturbances are active. The project was divided into several work packages together forming a technical solution, which should make it possible to better ensure that a vehicle combination can stay in its stability envelope during emergency braking. Some work packages were accompanied with a research question (RQ) in order to clarify what to prioritize. The work packages and research questions were (for more details see [11]):

WP1: Characterization of stability envelope of the vehicle combination, where both yaw and roll stability was to be included.

RQ1: What are the stability envelopes for the selected combinations and the influence on the stability envelope when using different motion actuators?

WP2: Control design of motion control system with actuator coordination.

RQ2: How is the vehicle stability envelope from WP1 fused with actuator limitations, i.e. limits and rate of achieving the requested vehicle states?

WP3: Control design and prototyping of front active steering system.

RQ3: How can the stability envelope and the ability to achieve the vehicle states from WP1 and WP2 be informed as the steering force feedback? Specifically, when steering force feedback is used for emergency trajectory guidance?

WP4: Automated emergency braking with steering force guidance in selected scenarios.

RQ4: How should the steering force feedback be designed to guide the driver during automated emergency braking to follow a desired lane trajectory until full stop is reached while disturbances are compensated for and the vehicle's stability envelope is considered?

WP6: Function development and Verification

WP7: Academic Lic degree

(**WP5** and **WP8** were initially defined, but not in scope for this project.)

4. Project realization

The project ran according to what was planned. All partners have also contributed as intended in total. Some delay however arose before one of the partners could start to contribute. This was due some difficulties in agreeing on project terms, which were eventually sorted out.

Content wise, the project group has developed verified functionality for force feedback in a commercial heavy vehicle. This functionality has been used in different experiments in order to better understand the impact on human drivers. The functionality has thereafter been extended to support combined braking and steering, and where both actuator limitations and driver limitations are considered.

Here are some of the important actions that were performed in the project

- Thorough literature reviews were conducted in all areas researched to gather relevant state of the art material.
- Hard quality constraints were put on software and hardware developed in order to make it reusable also after the project.
- Function development was supported both by computer simulations and truck testing.
- Three clinical tests were set-up with subjects on a test-track to analyse human response when involving developed functionality.
- The involved Phd candidate took part in relevant courses at Chalmers.
- Several conferences were visited to exchange ideas with other researchers.
- Internal project steering group meetings were held.
- An external group of experts were gathered at one occasion to give advice on the work performed.

5. Results and deliverables

The project has developed dedicated functionality and knowledge to meet the intended outcomes from the project. The different research questions have also been answered to the best extent possible; most of the answers have indirectly been formulated in publications according to:
RQ1 [1,5,6]; RQ2 [6,8,9]; RQ3 [2-6]; RQ4 [2-5].

5.1 Delivery to FFI-goals

The project's aim is to contribute to the overall vision of 50 % less fatalities in traffic by 2020 compared to 2007. More specifically, this project has contributed in functionality towards developing safe commercial heavy vehicles. Here, the immediate design of the steering force feedback aims on guiding the driver during an automated emergency braking situation to maintain within the lane until full stop has been reached and automatically compensate for any disturbances to maintain the vehicle in the requested trajectory. This is to reduce the severity of one of the most common crash accident situations where a light vehicle comes into the wrong lane. Maintaining the commercial heavy vehicle in the lane will also reduce the risk of multiple vehicle crashes. Within the traffic safety area (as defined when the project started) this project was aiming on the C – part which is driver support, the interface between driver and vehicle.

This will contribute to that Volvo AB will remain world leading in developing safe commercial heavy vehicles.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Several of the involved executors within the project are also involved in other activities regarding development of new products. This creates good possibilities for transfer of research results directly to market implementation. A large share of the achieved results have furthermore also been spread outside the partner constellation in form of publications and participation in several conferences, see list below. Moreover, a certain part of the developed functionality was considered particularly valuable and therefore filed as a patent application.

6.2 Publications

[1] Nilsson, Peter, and Kristoffer Tagesson. Single-track models of an A-double heavy vehicle combination. Chalmers University of Technology, 2014.

[2] Tagesson, Kristoffer, Bengt Jacobson, and Leo Laine. "Driver response at tyre blow-out in heavy vehicles & the importance of scrub radius." Intelligent Vehicles Symposium Proceedings, 2014 IEEE. IEEE, 2014.

[3] Tagesson, Kristoffer, Bengt Jacobson, and Leo Laine. "Driver response to automatic braking under split friction conditions." 12th International Symposium on Advanced Vehicle Control (AVEC'14), Tokyo Japan. 2014.

[4] Tagesson, Kristoffer. "Truck Steering System and Driver Interaction." (2014).

[5] Tagesson, Kristoffer, Bengt Jacobson, and Leo Laine. "The influence of steering wheel size when tuning power assistance." International Journal of Heavy Vehicle Systems 21.4 (2014): 295-309.

[6] Tagesson, Kristoffer, Leo Laine, and Bengt Jacobson. "Combining coordination of motion actuators with driver steering interaction." Traffic injury prevention 16.sup1 (2015): S18-S24.

[7] Siregar, Syarifah, "New Design of Human-Machine Interaction for Steering Articulated Truck Combinations". Master thesis TU Delft, Delft University of Technology, 2015.

[8] Sinigaglia, Andrea, "Actuators Coordination of Heavy Vehicles using Model Predictive Control Allocation". Master thesis Universitat de Barcelona, Universitat de Barcelona, 2015.

[9] Sinigaglia, Andrea, Kristoffer Tagesson, Paolo Falcone and Bengt Jacobson. "Coordination of Motion Actuators in Heavy Vehicles using Model Predictive Control Allocation", Submitted to conference

[10] Tagesson, Kristoffer, and David Cole, "Advanced Emergency Braking under Split Friction Conditions & the Influence of a Destabilising Steering Wheel Torque", Submitted to journal

7. Conclusions and future research

The suggested hypothesis that force feedback used for preventing vehicle stability envelope violation would be effective turned out partly accepted and partly rejected. Humans respond very differently to force feedback depending on the amount of time available to process the information. This means that force feedback can be very effective in representing slow events, such as over-steer. But in the case of a rapid event, where the time from stimuli to response has to be short, force feedback is not as effective. The underlying reason for this lies in the human neural system, and whether the stimuli activate reflex or more conscious actions. In rapid events it would therefore be necessary to support the driver, not only by providing force feedback, but also to use other actuators to affect the motion of the vehicle, until the point where the driver acts deliberately. In the case of emergency braking with an acting disturbance this means that it is uttermost important to limit the disturbance both by planning and also by limiting the activation of the brakes to a level where the driver can be expected to cope with the disturbance. If other motion actuators, such as rear-axle steering, can be used to reduce the impact of the disturbance, in a way which is disconnected from the driver’s action, this will sometimes make it possible to maintain a short stopping distance. All these mentioned aspects were implemented and tested within the project.

A few years have passed since the project first started. At the time a lot of expectations were put into sensor-technology in detecting head-on collisions long before they happen. At present the field does not seem to meet these expectations. This means that in practise today a head-on-collision cannot be predicted early enough so that only emergency braking is sufficient to escape a collision. Therefore a new project [14] has been initiated to continue the work on reducing the number of head-on collisions by also considering the option of moving the heavy vehicle in the lateral direction. This sometimes allows a decision about avoidance to be taken later in time. This new project is planned to run for two years.

8. Participating parties and contact person

A. Volvo Lastvagnar AB – Project Leader: Inge Johansson
B. Sentient Sweden Ek.Fö. – Contact: Jochen Pohl
C. Chalmers tekniska högskola – Contact: Bengt Jacobson

9. References (other than those listed in Section 6)

[11] Application to FFI: “Active Steering Force Feedback for Commercial Heavy Vehicles”, FFI Project ID: 2012-00938.

[12] Traffic Safety Facts 2009 Data, Large Trucks, U.S. Department of Transportation National Highway Traffic Safety Administration, DOT HS 811 388, updated 2011.

[13] Berg Y., Analys av trafiksäkerhetsutvecklingen 2010 – Målstyrning av trafiksäkerhetsarbetet mot etappmålen 2020, Trafikverket, Publ 2011:113, 2011.

[14] Application to FFI: “Active Steering Force Feedback for Commercial Heavy Vehicles Step 2”, FFI Project ID: 2015-04817.