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TITLE:

Integrated vehicle systems for enhanced active safety

Topic:

- FUTURE AUTOMOTIVE TECHNOLOGY INTELLIGENT TRANSPORTATION SYSTEMS
 USER FRIENDLY AUTOMOBILE ADVANCED PRODUCTION AND LOGISTICS
 VEHICLES & THE ENVIRONMENT

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Abstract:

Today several manufacturers develop electronic steering system, so the electronic (electro-hydraulic) steering will be introduced rather soon in commercial vehicles as well. A steering system without a direct mechanical link between the steering and steered wheels will provide further opportunities for the intelligent powertrain, which will intervene into the vehicle directional control. One of the straightforward applications is the combined action of the brake and steering system based vehicle dynamic control. Although the brake system based ESP has many benefits (precise control of individual wheel slips, reducing the kinetic energy of the vehicle by the braking, etc.), some improvement opportunities are still there, especially in the pre-ESP field, namely in the slip regions, where the brake systems based control still silent, but the vehicle behaviour clearly shows the necessity of intervention.

This paper focuses on the control algorithm, which is responsible for the intervention and also contains simulated test results showing the effect of the steering intervention on the ESP.

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Keywords: vehicle stability, commercial vehicles, ESP, steer-by-wire

STATE-OF-THE-ART

The increase of the commercial vehicle traffic on our roads is the main reason of the development of enhanced electronically controlled systems. On the roads of Europe, the commercial traffic will be increased by about 60% within the next years. As a result the number of accidents will increase as well and traffic efficiency and traffic flow will suffer. Trucks will contribute over-proportionally to the accident numbers. In order to be able to control this growth and decrease – or better prevent – the number of accidents by reducing the gap between the dynamical behaviour of passenger cars and heavy vehicles, several systems will come to the market in the near future. These systems together will form an electronically controlled intelligent powertrain. This electronic control architecture is able to synchronize the different subsystems such as braking, steering, transmission, etc. Among these the electronic braking system is already state-of-the-art in the heavy classes since 1996. Today several manufacturers develop electronic steering system, because of many constraints in the driver's cabin (design, safety compromises), the electronic (electro-hydraulic) steering will be introduced rather soon in commercial vehicles as well. Although a steering system, without a direct mechanical link between the steering and steered wheels requires many conceptual changes in the vehicle electronic architecture (in power supply, communication, etc.), it will become a reality and will provide a further opportunity for the intelligent powertrain, which will intervene into the vehicle directional control. One of the straightforward applications is the combined action of the brake and steering system based vehicle dynamic control. Although the brake system based ESP has many benefits (precise control of individual wheel slips, reducing the kinetic energy of the vehicle by braking, etc.), some improvement opportunities are still there, especially in the pre-ESP field, namely in the slip regions, where the brake systems based control still silent, but the vehicle behaviour clearly shows the necessity of intervention.

THE X-BY-WIRE CONCEPT VEHICLE

To achieve an overall improvement in safety, a fully electronically controlled powertrain is necessary. The philosophy of the whole PEIT (Powertrain Equipped with Intelligent Technologies) project covered among others the development of the presented vehicle dynamic system is thus to build up an intelligent powertrain, which provides an interface to serve all accident prevention and driver assistance functions of the vehicle. Only kinematical task (the so-called motion vector or speed vector) is then necessary to tell the vehicle, where to drive, an approach which is successfully used for flight control (fly-by-wire) in the aerospace industry. The intelligent powertrain becomes the basis for an intelligent automatic control of the vehicle dynamics. More specifically, the so-called x-by-wire systems require driver requests to be sensed and interpreted appropriately so as to take proper account of the current driving conditions and environmental influences. These requests have to be translated into optimum steer, brake, and acceleration manoeuvres. The advantages of such safety and comfort increasing applications are well known.

The powertrain interface developed in the PEIT project will make it possible that steer-by-wire, brake-by-wire, shift-by-wire, accelerate-by-wire systems can be integrated to one system. To connect the distributed functionalities and their electronically controlled devices failure tolerant system architecture has to be developed. The architecture will

base on time triggered and event triggered bus and controller hardware including operating systems and added definitions for functionalities and their communication.

X-by-wire concept

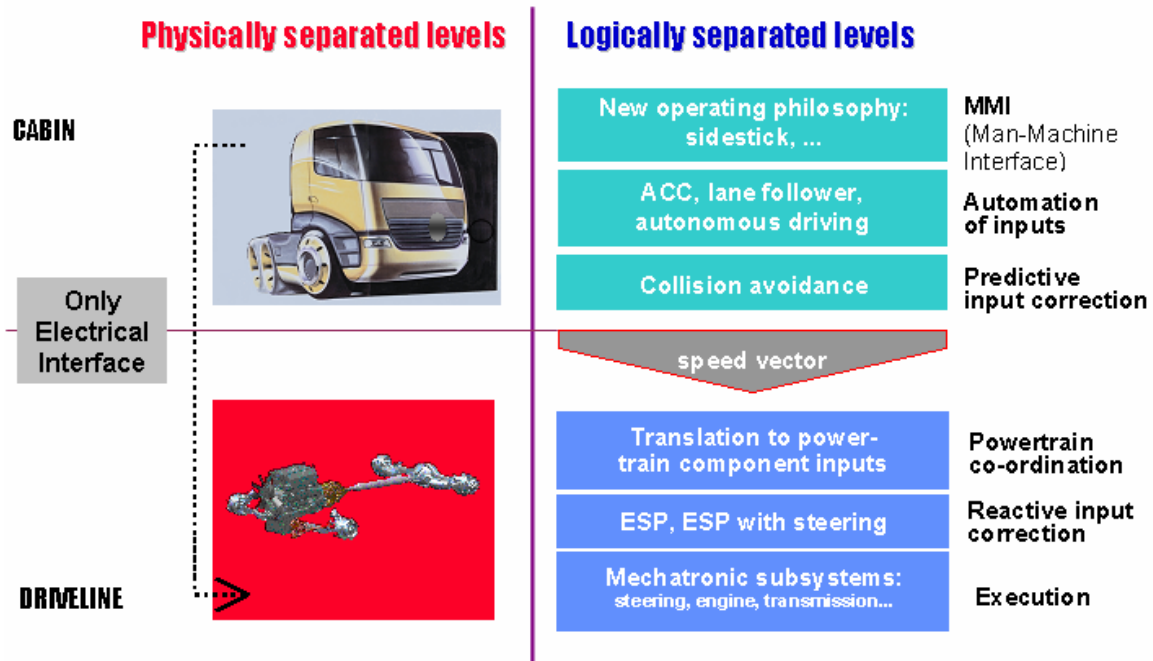


Figure 1 X-by-wire concept architecture

As a part of the PEIT project special attention was paid to the development of a vehicle dynamic control system, an ESP (Electronic Stability Program) that is enhanced by steering control and thus is more effective than differential braking of individual wheels alone. Active additional steering increases vehicle stability and reduces stopping distance under certain conditions. In this paper a single tractor control will be introduced. The steering enhanced ESP algorithm we focus on within this paper is a vital part of the ECU (Electronic Controlling Unit) of the X-by-Wire vehicle

VEHICLE AND CONTROL SYSTEM ARCHITECTURE

The most dangerous accident causes with heavy commercial vehicle involved are jack knifing, trailer oscillations, rollovers, lane departures and skidding. A substantially higher level of vehicle safety can be reached by preventing these safety critical driving conditions. To achieve this, some of the driving decisions taken by the driver have to be modified by some automatic control system which does not lead to the elimination of the driver from the control loop but influence his/her intervention. The only brake system based ESP system manipulates the tyre force vectors in order to produce the largest available stabilising moment as shown in Figure 2.

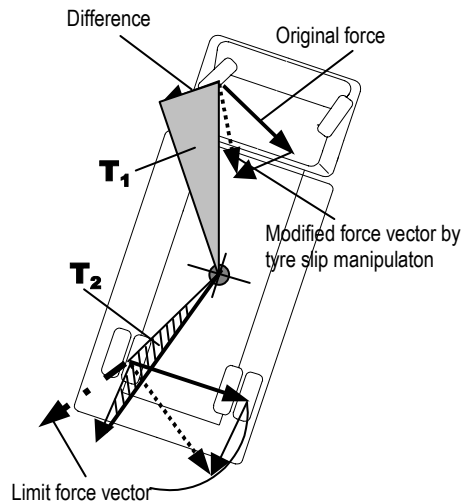


Figure 2 Operation of the brake system based ESP

The graphical representation of the desired control is as follows: find the maximum territory of shaded triangles, which represents the maximum available stabilising moment. The steering system based ESP's operation will be presented in a similar way.

Figure 3 shows the control system architecture of the combined system. There are 3 actuators in the system, as the brake, steering systems and the engine. All of them has an own ECU, which are able to receive command signals from the central vehicle stabiliser ECU, called ESP ECU. The pedal box including accelerator and brake pedal sends signals to the ESP, Brake-by-Wire and Engine ECU as well. The ESP ECU receives vehicle handling parameters like longitudinal and lateral accelerations, yaw rate and wheel speeds.

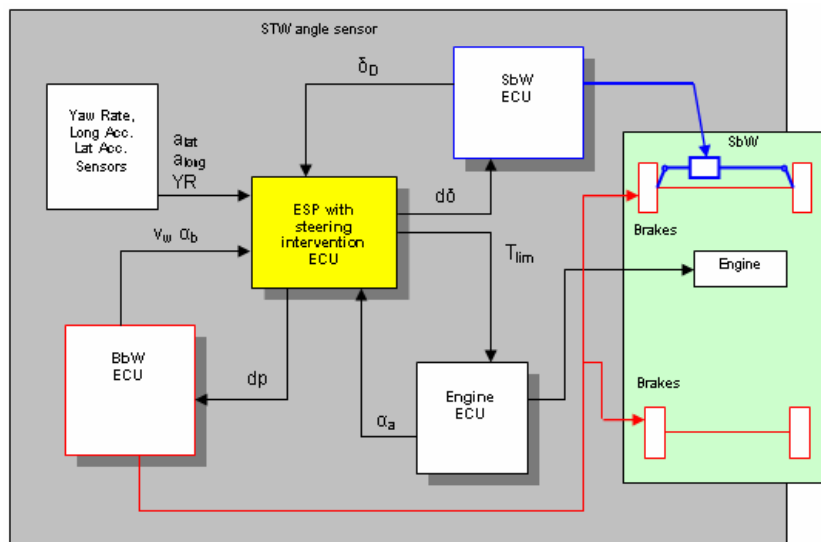


Figure 3 System architecture

The control logic calculates the difference between the driver's desired variables (as reference) and real motion variables. The yaw rate ($d\Psi/dt$) and the side slip angle (β) were

chosen as motion variables, because by using these 2 values both a simple controller and the state space representation can be programmed. The simple controller uses a reference vehicle model when computing the reference yaw rate and side slip angle, the target variables to follow. These are steady state variables at current values of the desired vehicle speed (from pedal positions) and steering angle input. The controller compares the actual (measured) values of the real (simulated) vehicle with the reference (desired) values that were computed from the reference vehicle model as shown in Figure 4.

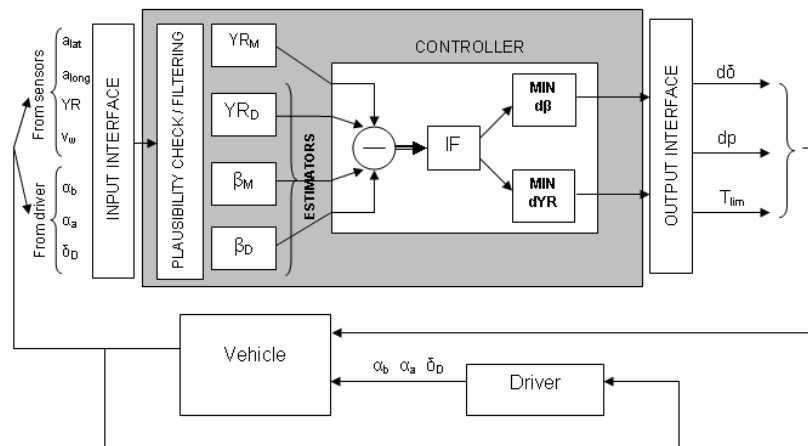


Figure 4 Control algorithm

The compensating yaw moment is generated by applying the brake pressures on different wheels and by steering the wheels according to the ESP intervention. The brake pressures will be limited by the ABS logic to prevent the wheels lock, however the ESP can change the target slip of the front wheels to enable bigger slip values. By bigger slip values the side forces on the wheels decrease, which can be necessary to harmonize the motion of the vehicle. There are cases when the side slip angle of the steered wheels is too big to add further additive angle, so in this situation the steering angle has to be limited.

TEST RESULTS

Testing Environment

There have been tests executed with the testing environment presented on the figure below.

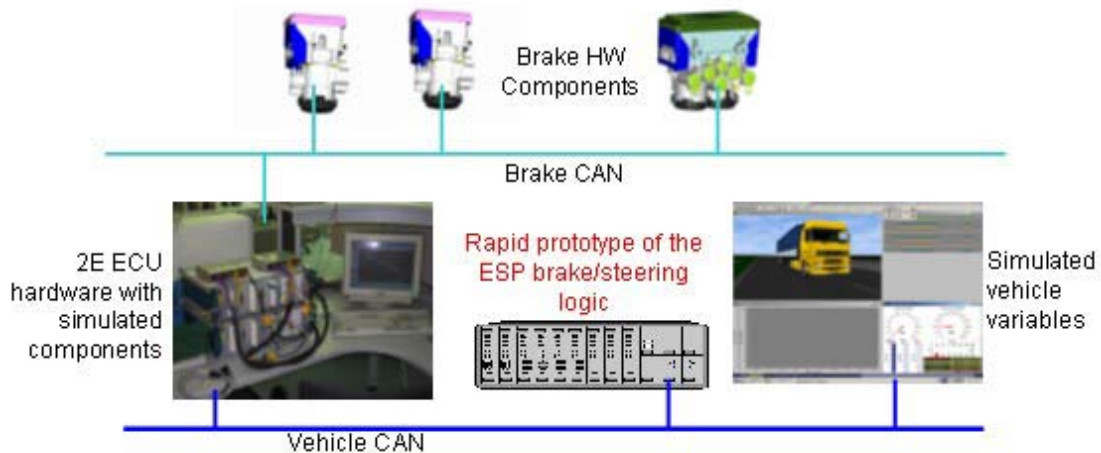


Figure 5 Test environment

The test vehicle (heavy duty vehicle) was simulated with a vehicle simulator SW. The simulated vehicle variables were transceived to the vehicle CAN communication line, the variables was received by the ESP algorithm running in a real-time rapid prototyping HW. The brake commands from the simulator SW and the ESP algorithm was sent to the Hardware-In-the Loop brake test bench, which executed the brake commands. The realized brake intervention and steering intervention commands were sent back to the simulator and applied by the simulator SW – the results of the ESP action can be observed on the simulation as the vehicle motion.

Test Results on μ -split surface

One of the major tests is the braking process on a road with unbalanced adhesion conditions (so called μ -split surface). In this test the vehicle brakes on a road with a high-friction surface (e.g. dry asphalt) on one side and a low-friction surface (e.g. ice) on the other side of the vehicle.

Particularity of this test is that the different friction coefficients on the two sides result in a yaw-moment generated around the centre of gravity of the vehicle which tries to spin the vehicle. So the arising yaw-moment has to be controlled by the brake system (ABS or ESP if available), but still the vehicle has to be stabilized with a counter-steering effort by the driver.



Figure 5 *Vehicle simulation test on a μ -split surface*

The advantage of the steering-enhanced ESP is that the steering intervention reduces the needed steering effort required from the driver to keep the vehicle stabilized. The table below (see Table 1.) shows that according to the aims of the customer the ESP can be attenuated in different ways:

- The ESP will have the same brake distance as the traditional ABS brake system, but the steering effort (Max. Steering Wheel angle) required from the driver can be significantly reduced. (Compare columns 2 and 3)
- The ABS can be modified so that the brake distance is reduced (that can be NOT solved without ESP with steering intervention because the driver alone can not cope with the increased yaw moment that spins the vehicle) though the driver performs a similar counter-steering than without any ESP assistance. (Compare columns 2, 4 and 5)

	μ -split 0.2-0.9 No ESP	μ -split 0.2-0.9 ESP with steering	μ -split 0.2-0.9 No ESP <i>Mod. ABS</i>	μ -split 0.2-0.9 ESP with St. <i>Mod. ABS</i>
Brake distance (m)	70	70	68	68
Max. STW angle (deg)	99	-9 / +20	145	95
Max. wheel angle (deg)	99	80	145	129
Max. sideslip angle (deg)	4.8	3.2	6.8	6.0

Table 1 Test results on μ -split surface

Note that when the steering-enhanced ESP is active, the steering wheel angle and the realized steering angle of the wheels differ.

Test Results on circular track

Tests were executed also on a circular track with medium friction surface (0.5 friction coefficient) while the truck constantly tries to accelerate. (See Figure 5.)



Figure 5 Vehicle simulation test on circular track

The truck being a rear-wheel driven vehicle turns to show oversteered behavior. The traditional ESP system is stabilizing this motion by reducing the engine torque and so the traction force, and by braking the outer front wheels if necessary. Still the driver has to counter-steer, that means he has to steer opposite to the circular path he is moving on. (See Table 2., column 2., negative data at the Steering Wheel angle)

	Traditional (Brake- based ESP) (min - max)	Steering- enhanced ESP (min - max)
Yaw Rate (rad/sec)	0,19 .. 0,27	0,2 .. 0,26
STW angle (deg)	-4,5.. -30,6	14,5 .. 20,5
Wheel angle (deg)	-4,5 .. -30,6	-9,4 .. -25,6

Table 2 Test results on circular test track

With the steering-enhanced ESP the brake-intervention of the ESP is similar to the above mentioned, but as a result of the steering intervention the driver steers “normally” aiming the circular path, and the counter-steering is performed automatically by the Steer-by-Wire system in accordance with the ESP ECU. (See Table 2., column 3) Note that the driver steers to the right (positive values) but the wheels turn to the left (negative values).

CONCLUSIONS

The target of this paper was to summarize the actual status of the steering-enhanced vehicle dynamic control system development in the EU’s PEIT project. Results clearly show, that the undergoing development faces the right direction in order to produce vehicles that behave safer and more reliable.

Tests show that the demonstrated brake based ESP combined with a steer-by-wire system can significantly improve the vehicle’s dynamic behaviour especially under the following circumstances:

- Normal ESP situation (e.g. accelerating in a curve); instead of the harsh braking (only brake based ESP) caused by the “dead band” the steering responds earlier and smoother, this results in less aggressive interaction and quicker response.
- Braking under unbalanced μ -conditions (μ -split); the system can significantly reduce the stopping distance because of the modified Yaw Moment Control algorithm while the driver steering effort is also lowered as a result of the autonomous steering intervention (see Table 1).
- Braking in a turn under unbalanced μ -conditions; like the straight-line μ -split braking the improvement is significant: decreased braking distance by 5 m.

There are also satisfactory results under other circumstances, however the difference between brake-based ESP and steering enhanced ESP are not so remarkable:

- The Braking in a turn; this maneuver is rather difficult, since the lateral load transfer between the sides has to be taken into consideration. However, the improvement is measurable (still rather low) : 1m in brake distance
- Starting at μ -split conditions; the autonomous steering intervention of the algorithm reduces the driver’s required steering effort compensating the drifting

The above mentioned results of reducing the brake distances and making the dynamic behaviour of the vehicle more stable is “only” one major advantage of the ESP system complemented with the Steer-by-Wire system. As the results show, the proper tuning of this system gives us a big leap forward for achieving the aims of the PEIT project and the requirements of the vehicles in the future: the driver signals his wish, gives a “motion-vector” command to the X-by-Wire vehicle, and the powertrain consisting of intelligent mechatronical subsystems will execute the drivers wish with keeping the physical constraints of the road-vehicle system into consideration.

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REFERENCES

- (1) L. PALKOVICS, M. EL-GINDY “Design of an Active Unilateral Brake Control System for Five-Axle Tractor-Semitrailer Based on Sensitivity Analysis”, *Vehicle System Dynamics*, 24, pp. 725-758., 1995
- (2) KIHONG PARK et all “A Study for Improving Vehicle Dynamic Property using Hardware-in-the-Loop Simulation”, *Proceedings of AVEC 2002*, Hiroshima (Japan), 2002
- (3) MOTOKI SHINO, PONGSATHORN RAKSINCHAROENSAK, MASAO NAGAI “Vehicle Handling and Stability Control by Integrated Control of Direct Yaw Moment and Active Steering”, *Proceedings of AVEC 2002*, Hiroshima (Japan), 2002
- (4) Y. FURUKAWA, M. ABE “On-Board-Tire-model Reference Control for Cooperation of 4WS and Direct Yaw Moment Control for Improving Active Safety of Vehicle Handling”, *Proceedings of AVEC 1996*, Aachen (Germany), 1996
- (5) V. ALBERTI, E. BABEL „Improved Driving Stability by Active Braking of the Individual Wheels“, *Proceedings of AVEC 1996*, Aachen (Germany),1996
- (6) JOOST ZUURBIER, PAUL BREMMER “State Estimation for Integrated Vehicle Dynamics Control”, *Proceedings of AVEC 2002*, Hiroshima (Japan), 2002
- (7) O. MOKHIAMAR, M. ABE “Improvement of Handling Safety of Car-Caravan Combination by Direct Yaw Moment Control”, *Proceedings of AVEC 2002*, Hiroshima (Japan), 2002
- (8) M. LAKEHAL-AYAT, S. DIOP, E. FENAUX, F. LAMNABHI-LAGARRIGUE, F. ZARKA “On global chassis control: combined braking and cornering, and yaw rate control”, *Proceedings of AVEC 2000*, Ann Arbor (Michigan, USA), 2000