Development and Evaluation of an Experimental Platform for Steered Axles of Long Combination Vehicles

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***Abstract*— Long Combination Vehicles (LCVs) require different strategies in controlling lateral dynamics of the combinations to ensure optimal paths followed by the trailers. Steering more than one axle of the combination has been developed in previous works and now needs to be verified in real vehicle tests. This work thus developed an experimentation platform incorporating a rapid-prototyping system to provide the possibility of evaluating these algorithms on vehicle level. In this paper the solution is detailed as a Hardware-in-the-Loop (HiL)-platform linking a vehicle dynamics frame-work with two steered axles. In accordance with the automotive development process after the V-model, this allows to safely verify the functioning of both software and hardware before performing track-tests of the fully integrated system with all units of a LCV. This paper outlines the development and capabilities of the resulting experimental platform and gives a short example of its performance in a standard-maneuver, which is also used to proof the validity between simulation and HiL-environment enabling full system testing on vehicle level.**

I. Introduction

The driving behaviour of Long Combination Vehicles (LCVs) is in many ways different to that of single unit trucks and needs to be researched in great detail to gain an understanding of the vehicle's dynamic properties, that is equally detailed as it is for other vehicle classes. This will lead to development of better safety and assistance systems and thus reduce threat potential, accidents and fatalities involving this emerging mode of transportation [1].

The research project in which this work is embedded aims to develop an active dolly [2, 3], meaning that steering of two axles in a LCV will be autonomously conducted based on the driving situation at hand and various vehicle parameters (e.g. speed, steering wheel angle). This control algorithm is a result of previous works and shall now be executed on a rapid-prototyping system which controls two axles. To supply this connection between the hardware and control-algorithm implemented in the modeling-environment Simulink is the main-contribution of this work. This leads to lateral control over all units on vehicle level in a LCV. The platform developed in this work can be used to add steering for any two axles in a LCV.

The following points will be covered in this paper:

- outline of the development process of the experimental platform and presentation of the utilized hard- and software systems
- evaluation of existing hardware characteristics and delays and implemented measures to eliminate them
- discussion of a standard driving maneuver of a combination executed on the developed Hardware-in-the-Loop (HiL)-system
- a comparison between these HiL-maneuver and simulation results, which proofs the validity of the platform

The limitations of for this work are:

- HiL-applications of the system are covered only
- low-speed maneuvers are only to be considered
- all measurements in this work were undertaken with the axles being raised which eliminates friction

II. System Components

A. Base vehicle

The hardware base is a dolly manufactured by Parator Industri AB [4]. The steering system is based around the Electronically-controlled hydraulic Trailer Steering (ETS) developed and built by V.S.E. Vehicle Systems Engineering B.V. (VSE) [5] with two hydraulically steerable axles. It was originally meant to be used in trailer steering as an after-market system and thus does not tie in with any of the truck's communication networks or sensor data. This makes it manufacturer independent and very robust. The ETS solely relies on the articulation angle between the leading and following unit and the speed of the combination. The articulation angle is obtained via a dedicated sensor mounted on the king-pin of the respective unit, the speed-signal is gathered from the ISO-11992 Controller Area Network (CAN).

B. Rapid-Prototyping System

To execute the previously developed algorithms, that govern the steering of the LCV-combination, they needed to be ported to a platform, capable of interacting with the dolly and the tractor, while ensuring robust behavior during run-time. It was decided to incorporate the MicroAutoBox II (MABII) [6] by dSPACE [7], a real-time platform for its advantages in automotive environments with a vast selection of in- and outputs for interfacing with vehicular communications systems (CAN, Ethernet, FlexLink). It conveniently ties in with Simulink, which was used for algorithm development, for code-generation. The tool-chain furthermore comes with the supporting tool ControlDesk to easily provide logging and monitoring during run-time as well as control over the simulation variables' states.

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C. Vehicle Dynamics Simulation

To evaluate the dynamic performance of the LCV on vehicle level Volvo Group Truck Technolgy's Virtual Truck Model (VTM) library came to use. It is a library developed in and for Simulink environment and permits the simulation of truck dynamics based on a multi-body model for the kinematic relation and a parametrized tire model using the magic formula.

III. HiL verification setup

In accordance with the process of the V-model [9] it was deemed necessary and safest to verify both hardware, software, and the integrated algorithm in cooperation with the system in a HiL-test.

The VTM library includes a lot of processing-intensive sub-models (tire models, vehicle parameter sets) which lead to processing power not sufficing to allow for VTM's execution in the dSPACE environment on the MABII. To perform HiL-testing it was thus necessary to split the computational load and accomplish real-time data exchange between the hardware controlling-system on the MABII and the rest of the simulation which will be run parallely in Simulink in real-time on a standard PC. Though there are dedicated real-time platforms available to achieve real-time execution it was decided to rely on a standard PC to minimize costs.

Figure 1 illustrates the distribution of the HiL-setup's different components according to the Volvo Group Technology functionality model [10] over two computers, the MABII and the actual hardware (axles, hydraulic control system). The Vehicle Motion Management (VMM) consists of the previously developed controller which is executed on the simulation PC and the steering interface executed on the MABII. For track-testing it is necessary to also port the controller for execution on the MABII to have one closed off system.

A. Modification to base system

The sensors described in II-A were discarded and replaced by an artificial signal emulating the original message structure. By using the inverse function of the original mapping of articulation angle to steering angle, it was possible to command the desired steering angle. The base system has one CAN for both axles, resulting in one common steering angle for the both of them. By splitting this CAN into two separate networks, it is possible to actuate the axles independently.

IV. Characteristics and Implemented Measures

Three characteristics mainly influence the behaviour of the system:

1) If a constant steering-angle is requested over a certain period, the hydraulic system will slowly fall back to the middle position. This needs to be eliminated because turning maneuvers or shunting situations often require maximum articulation for longer timespan. Figure 2 shows this decline, for constant angles.

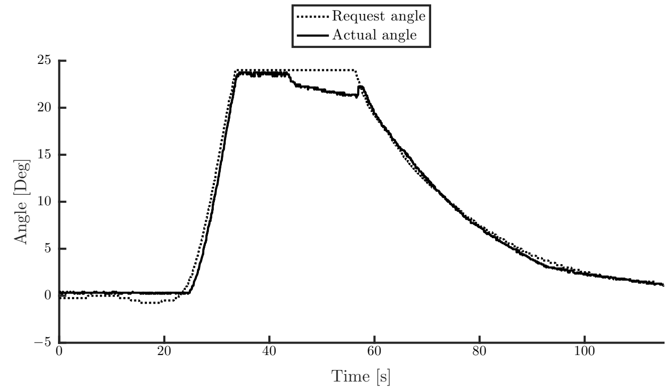

Fig. 2. Decline of steering angles for constant requests

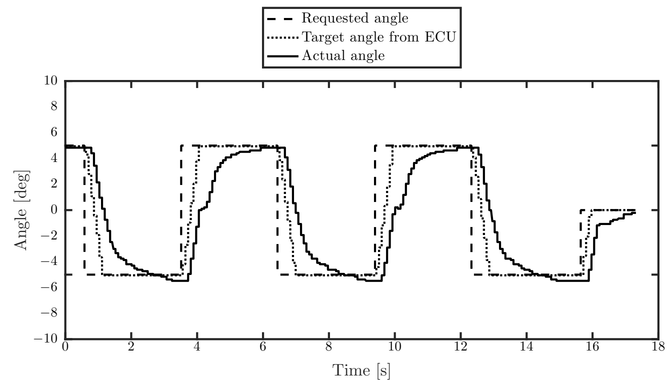

Fig. 3. Delay between requested angle and actual angle

2) Around the middle-position the steering does not react towards small changes. The legacy system has a dead band for articulations between +/-2 degrees. For the original application this is useful to ensure a straight path of the vehicle. For this experimental platform however consistent control over the complete range is desirable. This is to also enable small articulations of the axles which is especially called for at higher speeds, where steering angles are a lot smaller.
3) The steering system has a response time, composed of the normal inertias of the hydraulic system and an additional delay introduced by filtering and noise-canceling in the legacy system. This delays can be gathered from figure 3.

Measures to address these issues were:

1) To avoid the decline for constant requests, a periodic rectangular function with a small amplitude was added to the requested value and then fed forward to the Electronic Control Unit (ECU). This is shown in figure 4.
2) A Pulse Width Modulation (PWM) around the zero-articulation position reaching out of the dead-band was implemented for requested angles lying within this range.
Figure 5 shows the working principle of this measure. The mean value of the request to the ECU equals the desired request from the steering algorithm. The

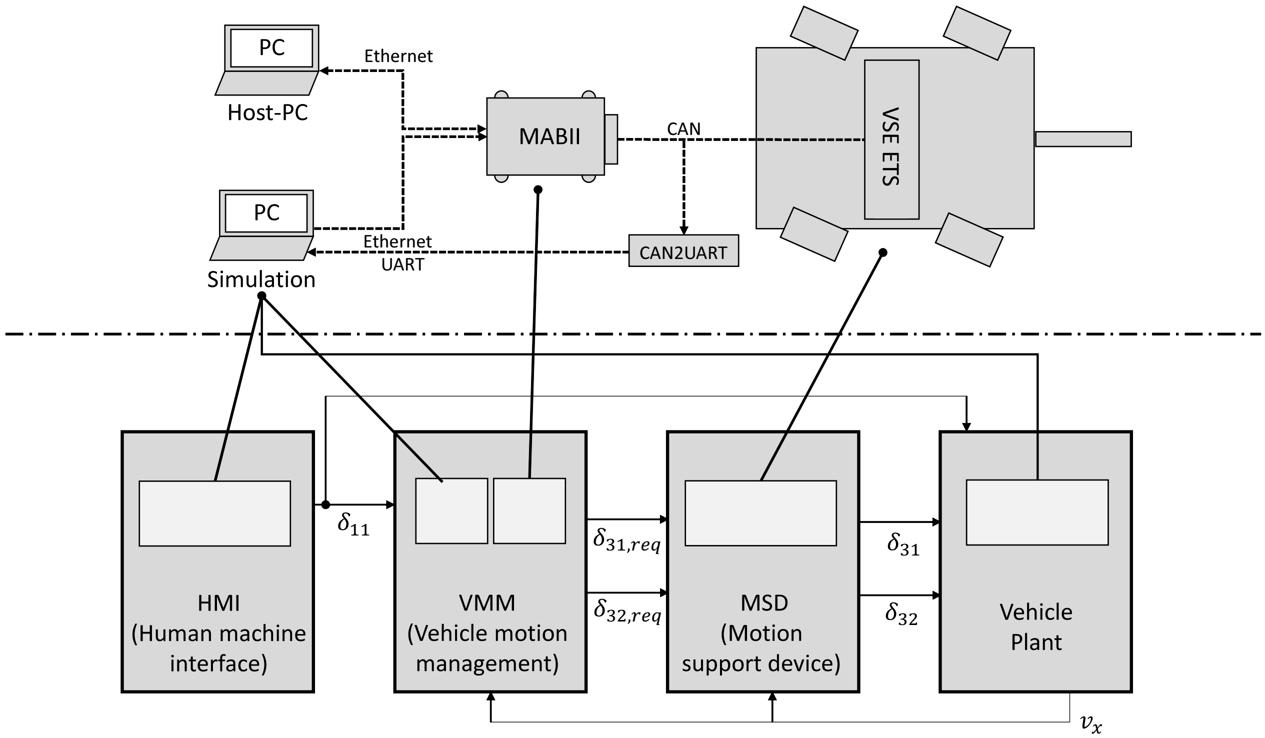

Fig. 1. Overview of HiL-simulation, distribution of sub-functions over different physical platforms (top) and correlation to Volvo functionality architecture (bottom)

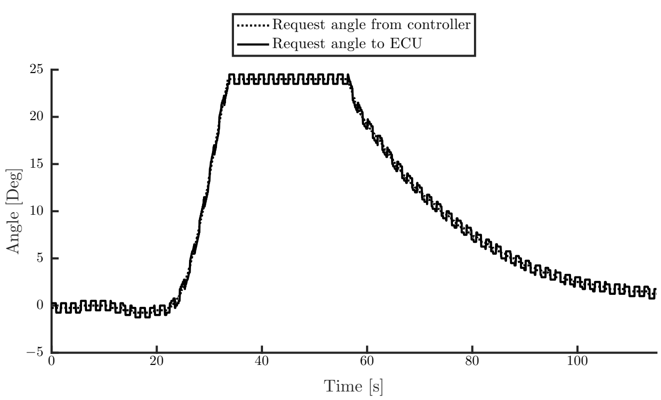

Fig. 4. Adding a pulsating function to the original request to feed forward to the ECU

pulse function oscillates between specified amplitudes outside the dead band. Through the inertia in the hydraulic system smaller angles can be accomplished, too.

3) Exactly determining the delay period made it possible to account for it in the calculations for initial testing, where a feedback-loop was not present and the speed was still sufficiently low. A value of 0.26 s for the front axle's reaction time and 0.30 s for the back axle's respectively are too high for higher speeds.

The introduced noise shown in figure 4 around the desired request value was also implemented in order to keep the hydraulic system active and thus eliminating

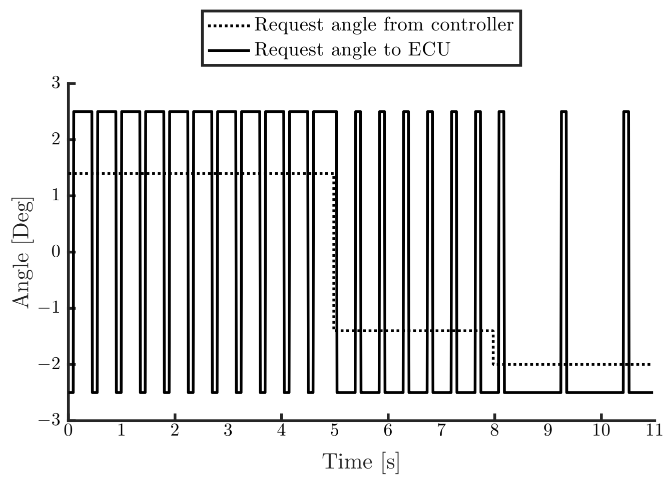

Fig. 5. Sketch of working principle of the implemnted PWM to circumvent dead band

some of the inertia.

V. Showcase Maneuver

To briefly show the general functioning and to give the reader insight into a practical application of the project, a standard driving maneuver was performed on the platform in the outlined HiL configuration. As an example the U-turn was chosen, for its relevance in everyday driving and the fact that it shows some of the characteristics of LCVs distinctively. It was executed at a longitudinal speed of 2m/s, thus resulting in a turning radius of approx. 16m. To ensure consistent behaviour over all measurements, the steering-angles of the truck were pre-programmed. As visible from figure 6, the truck does not leave the turn in a perfectly straight path. However this is not really relevant to this verification, as discussed further on only matching between the two environments is called for.

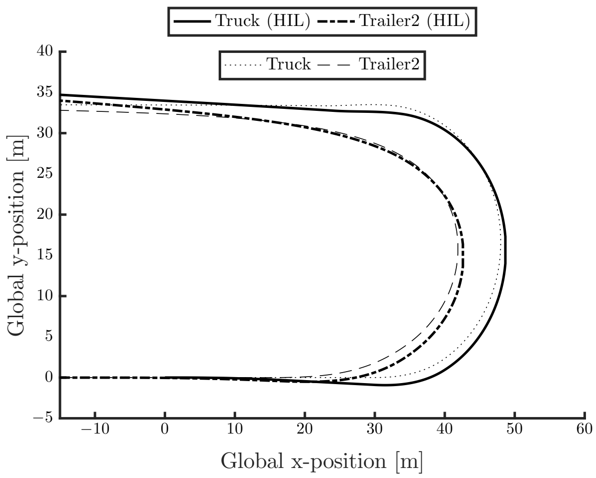

Fig. 6. Path of Tractor and Second Trailer for HiL and Simulation

Figure 6 shows the behaviour of the different units of the combination both for the developed platform in its HiL-configuration as well as the performance in the simulation environment. This gives the opportunity to compare between the two different stages of abstraction in the V-model, thus verifying the correct functioning of the actuated axles before executing further testing in the V-model:

It clearly shows in figure 6 is the phenomenon, that the second trailer does not follow the tractors path exactly. This is called off-tracking and minimizing it with an adequate actuation strategy is one of the major points within this research project. However this shall only be a brief mention in this publication.

The main point of figure 6 however is, to show the congruence of the resulting trajectories of the simulated environment and the HiL-setup.

VI. Conclusion

A platform which provides steering of two axles in a truck-combination was developed. Both axles can be steered independently.

A compact software interface for the algorithm development process was created, enabling access to the platform's hardware in the native Simulink environment. This interface already includes first safety functions to limit undesired inputs. Based on experience from simulations, further rules can be conveniently implemented. This enables the development of steering algorithms and functions on an abstract level without the need to consider lower level hardware issues.

The experimental platform was linked with a vehicle dynamics framework to form a HiL-system, which enables safe evaluation of a whole combination on vehicle level with two axles as hardware in the lab. The correlation between the simulation results and the HiL-tests was achieved accurately enough to continue with track testing.

VII. Acknowledgement

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