Development and evaluation of an experimental platform for steered axles of long combination vehicles

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***Abstract*— High Capacity Transport (HCT)-vehicles require different strategies in controlling lateral dynamics of the combinations to ensure optimal paths taken by the trailers. These steering algorithms have been developed in previous works and now need to be verified on the track. This work thus implemented a dolly experimentation platform incorporating a rapid-prototyping system to provide the possibility of evaluating these algorithms. The solution is detailed as a Hardware-in-the-Loop (HiL)-test linked with a vehicle dynamics framework in this publication. Results for this setups utilizing the aforementioned algorithms are presented and discussed. Nevertheless it is possible to run the outlined solution on-track, for which some suggestions are given at the end of this work.**

I. INTRODUCTION

The driving behaviour of HCT vehicles 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.

The research project in which this thesis is embedded aims to develop an active dolly, meaning that steering will be autonomously conducted by the dolly based on the driving situation at hand and various vehicle parameters (e.g. speed, steering wheel angle). This abstract control algorithm will be executed on a rapid-prototyping system which is linked to and controls the dolly. To supply this connection between the hardware and control-algorithm implemented in the modeling-environment Simulink is the main-contribution of this work.

The following points will be covered in this paper:

- hardware and software utilized to achieve HiL verification for an active converter dolly
- evaluation of existing delays in the implementation and their consequences
- discussion of three standard maneuvers for HCT-combinations executed on the developed HiL-system using the aforementioned controllers and a comparison with simulation results
- propose necessary changes to the set-up for taking the developed solution to the test-track in the future

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II. HARDWARE-SETUP

A. Base vehicle

The hardware base is a dolly manufactured by Parator Industries. 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) with two hydraulically steerable axles. It was originally meant to be used in trailer steering and as an after-market system does not tie in with any of the truck's communication networks or sensor data. This makes it OEM-independent and very robust. The ETS solely relies on the articulation angle between the leading and following unit on which the system is mounted and the speed of the combination. The articulation angle is gathered via a dedicated sensor mounted on the king-pin, the speed-signal is gathered from the ISO-11992 Controler Area Network (CAN).

B. Rapid-prototyping system (dSpace MicroAutoBoxII (MABII))

To execute the readily developed algorithms[1], that govern the steering of the HCT-combination 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 MABII by dSpace, 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. Furthermore it physically is very robust and has good logging possibilities.

C. Arduino

To convert from CAN-messages to serial output an Arduino Due together with a MCP2551 CAN-transceiver was used. This provided the feedback-loop from the hardware-system to the simulation environment during the HiL-testing.

D. interconnections between MABII/dolly/truck

III. SOFTWARE-SETUP

In this section a short overview of the utilized software and its interdependencies shall be given.

A. Virtual Truck Model (VTM)

To evaluate the dynamic performance of the HCT-combination Volvo's VTM came to use. It is a library developed in and for Simulink and permits the simulation of truck dynamics based on a multi-body model for the kinematic relation and a parametrized tire model around the magic formula. Many different HCT-combinations, road-situations and maneuver definitions come pre-defined with the tool-kit enabling a fairly quick implementation of full vehicle simulations.

B. *RTI-blockset*

dSpace's rapid-prototyping platform's connection with Simulink is centered around a library which provides access to all physical communication ports on the MABII, real-time execution on the target hardware and straight forward code-generation and -download. It was used to implement the CAN-communication with the ETS, the Electronic Brake System (EBS) and will be used to incorporate more signals from the truck's chassis-CAN in the future. Another use of the block-set was to ensure User Datagram Protocol (UDP)-communication within the HiL-testing, as the Ethernet-port on the MABII was used to supply data from the hardware system to the simulated sub-systems.

C. *ControlDesk*

As the simulation is executed on the MABII it is possible to access representations of all blocks and their values and properties that are part of the abstract Simulink model which was generated to the MABII. It thus is possible to have a user-readable system-state monitor. A number of Graphical User Interface (GUI) creation tools permit fast development. During execution ControlDesk runs on a standard PC, which accesses the MABII's RAM via ethernet connection.

IV. HiL-architecture

VTM includes a lot of processing-heavy 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 and have a lean work-process without extra steps of code conversion to different platforms. Figure 1 illustrates the distribution of the HiL-setup's different components according to the Volvo GTT functionality model over two computers, the MABII and the actual hardware. The Vehicle Motion Management (VMM) consists of the controller previously developed which is executed on the Simulation-PC and the steering interface executed on the MABII. For track-testing it of course is necessary to also port the controller for execution on the MABII to have one closed of system. This was not yet possible to achieve for the tests at hand, as some blocks used within the controller-algorithm's Simulink were incompatible for real-time execution on the dSpace system.

V. Delays

VI. 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. 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 HCT-combinations distinctively. It was executed at a longitudinal speed of $2m/s$, thus resulting in a turning radius of approx. 16m. To eliminate ensure consistent behaviour over all measurements, the steering-angles of the truck where pre-programmed.

- explain off-tracking as a measure
- swept path deviation

VII. RESULTS AND DISCUSSIONS

VIII. RELATED WORKS

The limitation of this papers were mostly due to time constraints. The

IX. CONCLUSIONS

APPENDIX

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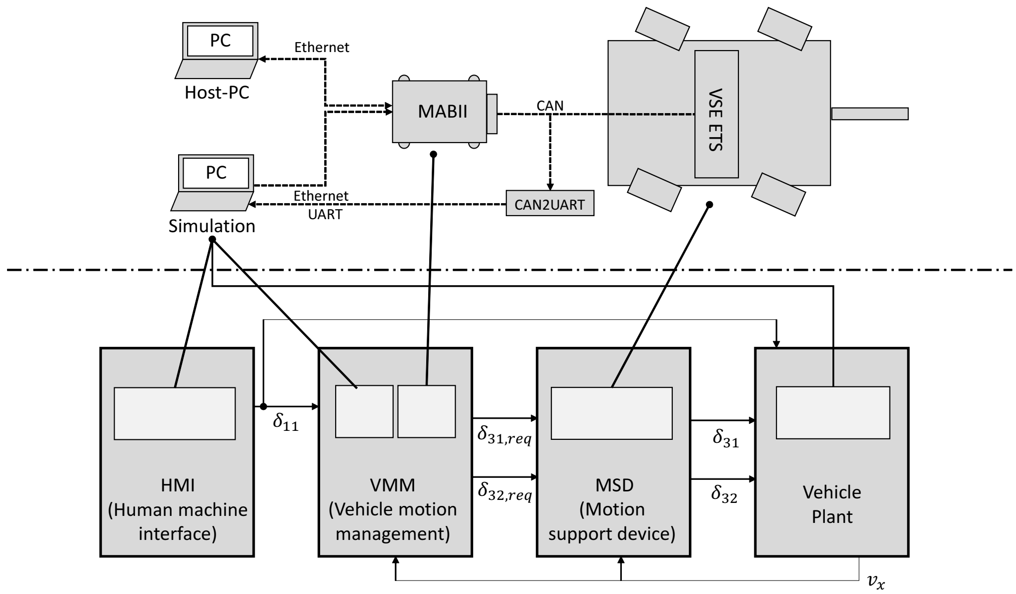

Fig. 1. Overview of HiL-simulation, distribution of sub-functions over different physical platforms (top) and correlation to Volvo functionality architecture (bottom)