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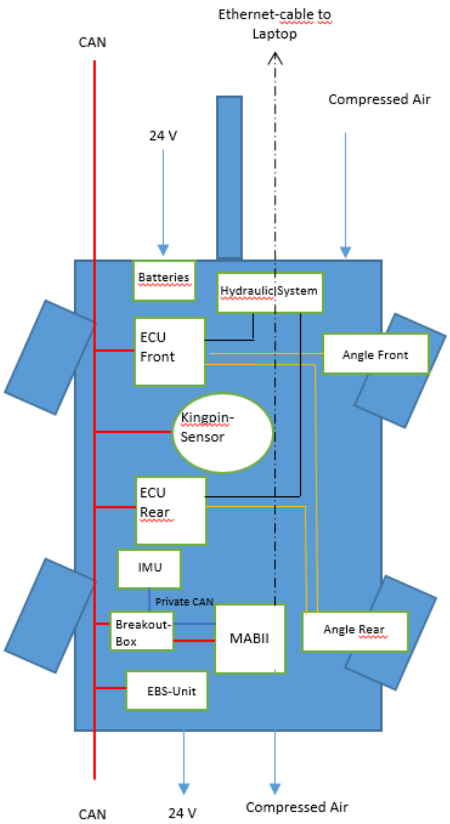

Active Steering Dolly for Long Combination Vehicles

Design of a Real-Time Control Interface for a Steerable Dolly

Master's thesis in Automotive Engineering

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Abstract

Keywords: Some stuff, More stuff, Stuff

Contents

1 Introduction

1.1 Purpose

Heavy goods-transport on the road has constantly increased over the last decades. Coupled with the stricter environmental regulations concerning CO_2-emissions and pollution, the call for more economical transport solution has led to the wider introduction of long combination vehicles. Those truck-trailer combinations have a longer history in geographical areas with low population density, mining and transport within factory sites where rail-road transport is not a viable option but transportation of large volumes and tonnages are called for. The prospects of saving costs on driver's salarys, reduced fuel consumption and decreased costs suggests the introduction of those combinations in other environments as well. Introduction of a new vehicle class leads to many challenges in safety, research and development, and legislation.

The driving behaviour of LCVs is in many ways different to that of standard 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 reduction in accidents and fatalities involving this emerging mode of transportation. Different usage patterns of LCVs have to be considered as well, when developing functions for LCVs. For example inner-city use is no prevalent use-case for LCVs, whereas highway safety features and handling properties at higher speeds are prime goals due to high percentage of highway-driving for LCVs.

Besides the technical implementation, socio-economic aspects have to be considered. Legislation has to be adjusted to allow for longer vehicle classes, including new certification processes and driver training. Furthermore infrastructure might have to be modified or reviewed to accomodate the needs and dimensions of extended truck combinations.

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). Furtheron braking capabilities are to be implemented to act in a similiar fashion as an electronic stability control system (ESC) by creating a yaw-moment countering undesired vehicle movements. This counter-steering will be achieved through wheel-individual brake-application.

The high-level 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 modelling-environment Simulink is the main-task out this thesis.

1.2 Objectives

The main-goals that are supposed to be achieved within this thesis' scope of work are:

- supply a software interface for the high-level Simulink control algorithm to be run on a rapid-prototyping system to control the active steering on an actual active dolly
- set up the physical hardware interface with the dolly; establish a suitable environment connection for the rapid-prototyping system on board of the dolly
- come up with a measuring solution to determine the processing delays in the sensing system as well as the delays introduced by computation and actuator reaction times
- supply a safety system that continously monitors the active steering system and triggers necessary warning
- supply an interface that allows to contiously determine the system's maximum actuation capapbilities depending on the system's current properties (loaded weight, speed, steering angle, yaw-behaviour)
- conduct extensive testing leading to a high-speed on-track demonstration

1.3 Limitations

The actual high-level algorithm to compute the desired angle for the dolly's steerable axles is not in the scope of this thesis. Nevertheless to establish an easier insight into the interfaces' parameters, an overview of the structure, in- and outputs of the underlying computational steering model is needed and shall be presented in chapter 3.

The hardware- and low-level control-system of the hydraulic actuators is in place already and thus will not be part of this thesis. It is supplied as turn-key software by the manufacturer and readily available on the dolly's electrical control units (ECU). Still some modifications are necessary to achieve the desired goals. The ECU's software version will be available fully calibrated and parametrized for the dolly at hand and thus provide a reliable working base to build upon.

1.4 Structure of this work

In the first two sections of this thesis a brief overview of the legal situation concerning LCV for different countries, the current state of the art and ongoing research in the field of LCV shall be presented (chapter 2). Furthermore an introduction to the model, that will be run on the rapid-prototyping system will be given (chapter 3). Those two chapters are meant to give an introduction into the matter and are in mainly based on literature review.

In the succeeding chapters the conducted work will be described in detail. Starting with a description of the utilizied hardware-systems and their interconnections in chapter 4, followed by detailing the different software-tools and environments running on those hardware-platforms in chapter 5. In chapter 6 the measuring concepts and theoretical details for the determination of the overall processing delays in the control-chain will be discussed. As at the planned high speeds and great inertia for testing safety is a major concern, extensive safety functions will be implemented and systematically evaluated. This will be outlined and discussed in chapter 7. After evaluating the safety of the system subsequently testing and validation is conducted and discussed in the following chapter 8.

The work closes with a discussion of the results collected during testing and a conclussion where the authors will try to give recommendation for pratical implemenation and outline future research work in the field.

2 Overview

2.1 Ongoing research

- LVC advantages/disadvantages (Baltin)
- safety aspects
- Environmental aspects
- development of saftey systems

2.2 Legal Situation

In Europe the permitted maximum length of a road train is 18.75 m and the maximum weight is 44 tonnes. But it is possible for countries to make exeptions from that rule.[12] For example in Sweden and Finland road trains can be up to 25.25 m long with a maximum weight of 60 tonnes.[13] Table 2.1 shows the maximum length and weight of LCV in different countries.

Table 2.1: LCV in different countries[13][11][1][5][3]

Country	Max. Length [m]	Max. Weight [t]
Sweden	25.25	60.00
Finland	25.25	60.00
Australia	53.50	132.00
USA(trailers without truck)	26.07	59.86
Canada	36.88	63.50
Mexico	31.00	75.50

2.3 Market overview for existing solutions

3 Steering Model

3.1 Overview of the model

- based on lit from MI-paper
- overview graph of model
- single track model
- filtering of inputs?
- feedback-loop
- start condition
- what can be concluded with the model?

3.2 Input parameters

- what parameters are used as inputs? dimensions, min/max
- explain feedback/inverse path

3.3 Real-Time implementation

- what had to be changed to allow for MABII execution?
- how will feedback loop be handled? item incorporate measurings?
- simulation step size?
- utilized computational method

3.4 Interface with Real-Time environment

- capabilities of system (see section 7.3)
- signals passed forward from environment + restriction
- actuator signals
- signal modification (correct frequency for CAN)
- safety flags/signals

4 Hardware Setup

4.1 Utilized dolly system

The utilized dolly by Parator Industri AB (Parator) is equipped with two steerable axles. They are controlled by an after-market solution supplied by V.S.E. Vehicle Systems Engineering B.V. (VSE), of which figure 4.1 gives an overview. Their product includes sensors, ECUs and hydraulic systems which come in a ready-to-mount housing, which is placed on the trailer/dolly. This solution is usually sold as a low-speed system for truck-trailer combinations to provide better maneuverability at low speeds in inner-city areas. Besides electrical power and compressed-air (see "2" in the figure) supply there is no connection with the truck in place. This allows for use with many different truck/trailer original equipment manufacturers (OEM), as no insight into proprietary CAN-communication is needed. In the original VSE system the two parameters that influence the actuation of the dolly's steering are vehicle speed ("4") and kingpin-deflection ("3") is considered. This deflection is the angle between the truck and trailer, which is measured by an additional kingpin-angle sensor supplied by VSE. Furthermore every steering-knuckle is equipped with an angle sensor to provide appropriate wheel-individual feedback for the VSE control-system. Furthermore a relatively simple diagnosis screen is available in the VSE-unit, which allows for set-up, calibration and parametrization to be done.[4]

VSE provides assisted steering up to a speed of 25km/h over which intervention until it reaches zero at 55km/h. At this treshhold the steerable axles are locked and thus behave like normal rigid axles. This according to the manufacturer is to ensure stability at higher speeds.[4] Locking the steering at higher speeds leads to a more predictable behaviour for the user and system robustness. However, performance during high speed maneuvers can be improved by uniformly steering the dolly as well.[6] The desired demonstration of the algorithm presented in chapter 3 will as outlined in the introduction to this thesis, include steering at higher speeds, thus a work-around had to be established.

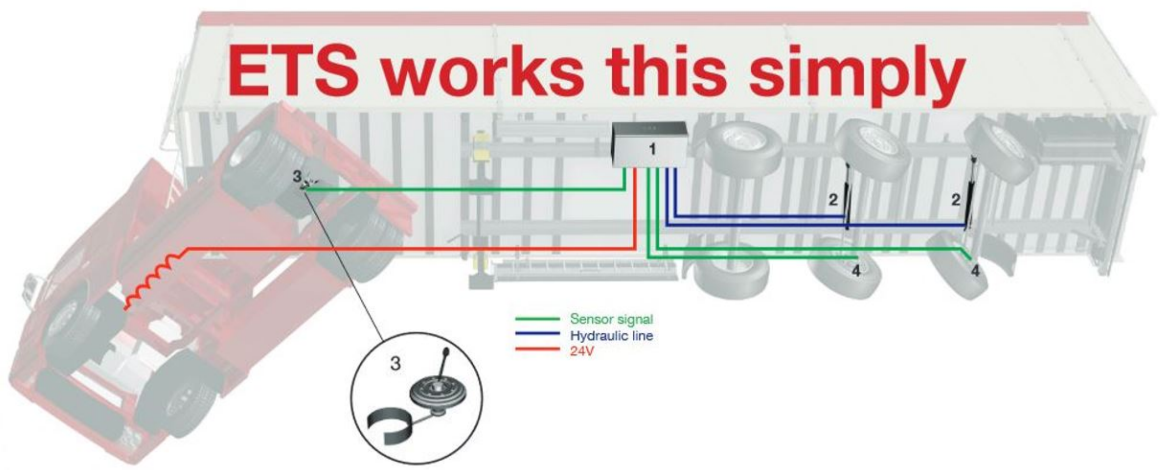

Figure 4.1: Active dolly legacy steering system supplied by VSE[4]

Short overview for the dolly, including:

- mechanical properties in short (weight, turning radius, max. tonnage)
- description of function (brake, steer, countersteer, lock at highspeed)
- difference low <=> high speed
- control system by VSE, diagnosis, display connection with truck
- system overview picture/schematics

4.2 Real-Time Environment

- mechanical properties of box (dimension, currents, mounting points in dolly)
- computational power/limitations
- explain interfaces with truck/dolly (abstract)
- explain technical realisation of HW interface (ZIF)
- explain rapid-prototyping
- robustness
- programming with software ref to 5.1
- runtime interface ref to 5.2

4.3 Interfaces with dolly

- private CANbus with AngleSensor for kingpin
- Vehicle CAN (ISO 11992, connector ISO 7638-2)

  brake by-wire

  EBS, ABS

  sensors for EBS, ABS

  signals/msgs on vehCAN
- physial interface => diagnosis outlet

4.4 Interfaces with truck

- CAN communication with truck
- steering system conncetion

4.5 Measurment Setup

4.5.1 On-board sensors

- king pin angle

  mounting

  CANcomm
- steering angle
- speed

4.5.2 Arduino Due

- clock frequency
- RAM/ROM
- ISP flash
- robustness, reliability, cost-effectiveness
- input/outputs analog & digital
- native I2C capability
- CANcomm except of physical layer/transceiver available (OSI reference!)

4.5.3 Inertial measurement unit

To determine the processing delays in the control chain (refer to chapter 6) as well as logging implementation for verification and analyses purposes a number of inertial measurement units (IMU) where utilizied throughout this thesis' work. The system at hand combined a gyroscope (L3GD20H), and an accelero- and magnetometer (LSM303D) into an IMU put on one circuit board[7]. This one-chip solution allowed for a convenient access to the sensor measurings, as the sensor outputs could be received via Inter-Integrated Circuit-protocol (I^2C) which eliminates the need for transducer. Furthermore a high-pass filter is integrated into the IMU's accelerometer, which allows for easier compensation of the immanent drift.

These units supply the measurings for three axes each at a maximum frequency of 1600Hz for the accelerometer and 757.6Hz for the gyroscope. [10][9]

5 Software Setup

5.1 Matlab/Simulink environment

5.1.1 dSpace RTI-Blockset

5.1.2 Volvo Transportation Model

5.1.3 Connecting with high-level steering model

5.2 ControlDesk monitoring environment

5.2.1 Maneuver control

5.2.2 Monitoring and logging

- data-format
- frequency
- synchronizing over different CANs

5.3 Arduino IDE and applications

6 Processing Time evaluation

6.1 Background

The desired solution is supposed to operate at any speed. For high speeds a quick processing and transmission time is required to ensure prompt and realtime intervention of the control system based on the measured input signals. If the delays induced by the different components in the complete system are known or can be estimated, they can be compensated for in the steering-algorithm running on the rapid-prototyping system.

The dolly is equipped with a system to determine the deflection angle of the drawbar. This is measured at the kingpin. The sensor's raw signal is then parsed and filtered in a low-level system which feeds the filtered signals to the CAN-bus, where it is picked up by the MABII. The filtering operation takes a certain time and thus induces a delay.

Furthermore the model running on the rapid-prototyping system needs a certain time to calculate the current desired steering angle for the dollys' wheels. This has to be determined as well. The steering mechanisms on the dolly are also a delay-inducer due to the inertia in the hydro-mechanic system. This is as well unavoidable, but when measured can as well be compensated for.

6.2 Measured input delay

- critical transmission time CAN (worst case)
- I^2C delay
- IMU-frequency
- msg-frequency from vehicle/dolly

6.3 Computational delay

- filtering on arduino
- averaging
- drift correction

7 Fault detection and system ability

7.1 Failure Mode and Effects Analysis (FMEA)

7.2 Safety concepts

7.3 Maximum capabilities of the system

- give indicator of maximum angle/angle rate
- describe "algorithm"/lookuptable
- explain underlying physical correlation (ref to MA from)

7.4 Warning and state-info system

- warnings from dolly ECU
- warnings from EBS
- warnings from vehicle
- 'own' error codes and warnings (e.g. logging, MABII related, arduino-IMU related)

8 Testing

8.1 Overview

8.2 Bench-Testing

8.2.1 ECU-setup

8.2.2 VTM maneuver verification

8.2.3 CAN verification

8.2.4 Fault detection system verification

8.3 Vehicle testing

8.3.1 System calibration

8.3.2 Actuator tests

8.3.3 Algorithm evaluation

8.3.4 Sensor testing

8.4 Track testing

8.4.1 Testmaneuvers

- lit research for standard maneuvers
- sine-wave
- outline critical parts of maneuver
- figure with SA over time
- expected behaviour from simulation

8.4.2 Testenvironment AstaZero

- overview of AZ
- restrictions of environment

8.4.3 Testmatrix

- checklist for launch
- parameters that very varied
- different runs
- planned maneuvers

8.4.4 Test setup and instrumentation

- detailed description of placement of sensors, wiring, logging-PC

9 Discussion

9.1 Results from bench testing

- lessons-learned?
- adaptation for future projects
- what was taken over for further tests?
- what couldnt be simultaed?

9.2 Results from in vehicle testing

- measured delay
- CAN-analysis
- robustness?
- reliability of safety features

9.3 Results from on-track testing

- what went good/bad?
- measuring problems?
- short descr. of accumulated data
- discussion of noise, filtering, systematic errors

9.4 Comparrison

- VTM <=> testing

10 Conclusion

10.1 Recommendation

10.2 Future Work

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