MSc Thesis proposal Volvo Group Truck Technology:

Motion Control and Energy Management of High Capacity Vehicles with Electrically Propelled Dolly

About us

Advanced Engineering & Vehicle Concepts is organized within Vehicle Engineering at Volvo Group Trucks Technology. We are responsible of preparing future trucks and transport solutions for all Volvo Group's brands and markets by managing and driving Advanced Engineering at Vehicle Engineering & Vehicle Technology. We develop the future competitive trucks to ensure the transport and energy efficiency for our customers and the society. We are open-minded and performance-oriented and honour to deliver tangible results.

Thesis Background

This project addresses the problem of CO2 emissions and energy consumption. High Capacity Transport, HCT, road vehicles show large energy savings, 10-30% and reduction of Total Cost of Ownership up to 30% [7], [8]. Hence, they are allowed in more and more countries. However, towing units intended for HCTs will be over-powered if they are used in non-HCTs, or lightly loaded HCTs. The proposed solution can be described as scaling the propulsion for HCTs.

The envisioned solution is to add electric propulsion on (converter) dollies. The dollies are "strategic" units in combination vehicles. Such solution will work both with diesel or electrically propelled towing units (trucks or tractors). Previous research, [4], [1], shows that an electrically propelled dolly enables additionally 10-20% energy savings for an HCT vehicle with diesel-propelled towing unit.

The following aspects are important to utilize electrically propelled dollies.

- The vehicle energy management needs to be predictive, typically over 1-10 km ahead, see [2].
- The control actions have to be distributed between the units, requiring an addition to the standard signal interface between units, [3].
- The trade-offs between safety and energy saving needs to be taken in to account, by distribution of propulsion and braking between different axles on different units separated by articulation points. This might cause reduced lateral stability. For example, the energy management controller sees that it is more energy efficient to only let the electric drive axle of the dolly to brake, for reducing the speed or for maintaining the seep downhill, rather than the other axles that have no electric drive, so that more energy can be recuperated. However, such a scenario should be allowed only if the safety and the lateral stability is assured. The lateral stability can be compromised because of the nonlinear behaviour of the tyres, and that there are more than two articulation points. Such a scenario is simulated, and the result is shown in Figure 4 below.

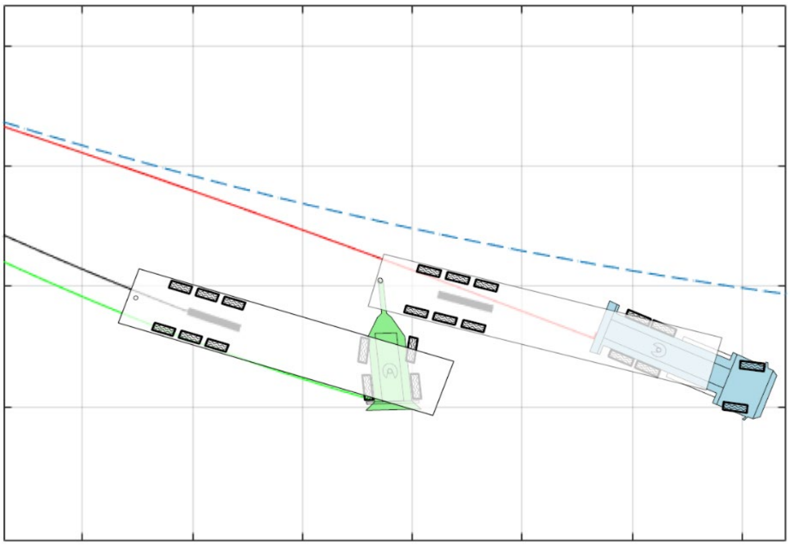

Figure 1: Dolly braking in a curve and slightly downhill road. The braked axle loses the lateral force due to combined slip effect in the tyres and the push of the last semi-trailer causes jack-knifing.

A similar instability might happen when the dolly pushes the front units during propulsion. Therefore, proper constraints should be defined in the energy management controller to avoid such scenarios, whereas energy saving should remain maximum. Real-time model predictive control of many states and control actions of a highly nonlinear system in presence of nonlinear constraints and long prediction horizons is a challenge of the project.

Objective or Research Question

How to implement the existing predictive energy and motion management code in an real HCT road vehicle for maximum energy savings for the whole HCT vehicle, taking the distributed propulsion and electrically propelled dolly into account?

Which parts of the control have to be vehicle-central and which can be unit-local?

How can energy savings for both manual and automated (cruise-like) driving be secured?

How should lateral stability be handled in real-time?

Deliverables (flexible)

- Validated Simulation model and Test vehicle (A-double with electric dolly) with consistent control interface (requests, actual quantities, capabilities, etc.)
- Implementation and verification of existing predictive control algorithms (optimized longitudinal speed and energy state of charge). Predictive methods from [4] will be used. They have additions for lateral stability. Proposal of signal interface between vehicle units.
- Influence of electric dolly, if used in an A-double, on the energy consumption and performance based standard PBS measures. Simulation study using models based on [5], [6].
- Implemented on-board predictive controller on the test vehicle and using Auto-box, Simulink and CasADi. Sequential programming algorithms from [4] shall be used for predictive energy management and motion control. The algorithms from [4] are based on physical models and can consider the important phenomena, e.g. road topography, curvature and limitations due to lateral stability, in a computational efficient way.

Important phenomena, related to well-known “jack-knifing” and “stretch-braking, forces the models to be nonlinear with respect to axle propulsion and brake forces times articulation angles, can be handled with sequential programming. The prediction should optimize the state trajectories of vehicle longitudinal velocity and energy storage state of charge and the longitudinal force distribution between axles and units.

Requirement on student background:

Talented master students in Control or Mechatronics with some knowledge of optimal control and programming. Please submit your CV and transcripts to toheed.ghandriz@volvo.com.

Supervision and examination:

Volvo Group Truck Technology, Advanced Vehicle Engineering.

Thesis Level: Master

Language: English

Starting date: Spring 2022

Number of students: 1 or 2

Resources: The student(s) will be given a laptop, required software and the access to the test vehicle and equipment. Also, the optimal control code that is theoretically developed for the objective of this thesis will be provided to the students.

Physical location:

Mainly a university in Sweden, but students are welcome to sit also at VGTT occasionally.

Contacts:

Toheed Ghandriz, toheed.ghandriz@volvo.com, toheed.ghandriz@chalmers.se

Lena Larsson, Lena.Larsson@volvo.com

Johan Lindqvist, johan.a.lindqvist@volvo.com

Bengt Jacobson, bengt.jacobson@Chalmers.se

References

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[2] Uebel, Murgovski, Tempelhahn, Bäker, *Optimal energy management and velocity control of hybrid electric vehicles*, IEEE Transactions on Vehicular Technology, vol. 67, no. 1, pp. 327–337, 2017.

[3] ISO, *ISO 11992 Road vehicles – Interchange of digital information on electrical connections between towing and towed vehicles*, 2003.

[4] project: Energimyndigheten/FFI, *Distributed Propulsion in between Vehicle Units in a Long Vehicle Combi-nation (LVC)*, Energimyndigheten FFI Diarienr: 2015-004985, projekt nummer 41037-1. 2015-2019. https://research.chalmers.se/en/project/?id=7036

[5] project: FFI with Finland, *Performance Based Standards II*, Chalmers project web page: https://research.chalmers.se/en/project/8350

[6] project: *COVER – Real world CO2 assessment and Vehicle enERgy efficiency*, https://research.chalmers.se/en/project/8239, 2018 – 2021.

[7] T. Ghandriz, B. Jacobson, L. Laine, and J. Hellgren, Impact of automated driving systems on road freight transport and electrified propulsion of heavy vehicles, Transportation Research Part C: Emerging Technologies, vol. 115, no. 102610, 2020. https://doi.org/10.1016/j.trc.2020.102610

[8] T. Ghandriz, B. Jacobson, L. Laine, and J. Hellgren, Optimization data on total cost of ownership for conventional and battery electric heavy vehicles driven by humans and by automated driving systems, Data in brief, no. 105566, 2020. https://doi.org/10.1016/j.dib.2020.105566