Predictive control for complete vehicle energy management

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Summary

The purpose of this (half-year long) project is primarily to bridge the gap between Chalmers' successful and finished projects in energy management during Phase 2 of SHC and a planned continuation project during Phase 3. The latter has been prepared in a pre-study and approved by the steering group, but funding of a continuation project has not yet been decided.

The industrial challenge underpinning this research is how to fully realize the potential fuel savings offered by hybridization of vehicle powertrains. In short, this amounts to control the power flows in the powertrain, as well as the engine and the gear states, so that available information about the driving mission is utilized to minimize fuel consumption. This control task is often referred to as *energy management*.

Previous work, which this projects builds on, has been conducted within the strategic research area (SFO) Chalmers Energy Initiative (CEI), as well as in the SHC project with PhD student Viktor Larsson. The idea is to further extend the hierarchical control architecture and algorithms, previously developed for predictive energy management of conventional and hybrid vehicles. Within this project, the following activities have been conducted:

- A seminar on energy management has been organized at Scania and DAF Trucks N.V.
- Extensions of the control architecture to take into account information about surrounding vehicles has been investigated
- Initial studies have been made on the problem of energy management of complete vehicle platoons

A couple of publications have been submitted on these topics, and an additional manuscript is in preparation. There are, however, many remaining issues to investigate, and the project team with its reference group has proposed topics for a future continuation project.

The project has had a reference group with members from AB Volvo, Scania and Volvo Cars.

General project description and background

This project builds on Lars Johannesson Mårdh's and Nikolce Murgovski's research on control architecture and algorithms for predictive energy management of conventional and hybrid vehicles. This research has links to the previous SHC PhD project with Viktor Larsson but has been conducted as part of the strategic research area (SFO) Chalmers Energy Initiative (CEI). The algorithms have so far only focused on optimizing energy management in a vehicle with information about speed limits and road gradient.

The proposed control architecture and algorithms allow extension with information about the surrounding vehicles and traffic flows, which is the first step toward autonomous driving. However, if the control system should be applied to autonomous vehicles and achieve maximum fuel savings, there are many unsolved questions and challenges: which is the best distributed control system for road trains of conventional and hybrid vehicles; how can convex optimization be used to reduce the computational requirements; how can algorithms be extended from mainly motorway driving to city traffic; how should the wear models be included; etc. The aim of this project has been to explore some of the issues and to provide input to a major continuation project, dealing with these research challenges.

A minor part of this project has been to support the final stage of a PhD project at Chalmers, where Mitra Pourabdollah has presented a thesis on the optimization of plug-in hybrid vehicles.

Achieved results

Part of the results of this project is based on a model predictive control architecture that divides the energy management problem into three layers that operate with different update frequencies and prediction horizons. The top layer plans the kinetic and electric energy in a convex optimization problem, the medium layer plans the gear and powertrain mode in a dynamic program, whereas the lowest control layer tracks available references in real time. Both the top and the medium control layers employ predictive road information, while the top control layer also incorporates information about the surrounding vehicles and traffic flows.

Research results for a predictive cruise controller that safely keeps distance to surrounding vehicles are presented in [1], where it is also shown that predictive information of the movement pattern of surrounding vehicles can be incorporated into the convex optimization in order to minimize energy losses.

When a platoon with multiple vehicles is formed, limited information from the top control layer can be shared between the vehicles to minimize energy losses of the entire platoon. By modeling the air drag with affine (linearized) relations, it is possible to optimize the energy management in a centralized convex program, or by applying algorithms from distributed optimization, without sharing sensitive information. It is shown in [2] that optimized energy management can be achieved by sharing only the optimal time trajectories (as a function of distance) from each individual vehicle. Neither of the vehicles needs to reveal any other details about the energy-management strategy.

Another part of the results is based on adapting a model predictive control to complex powertrain configurations. A method for applying convex modelling and optimization of electrically supercharged internal combustion engine vehicles has been presented in [4], [5]. Model predictive control of a hybrid electric powertrain with an electrified waste heat recovery system has been presented in [6]. Finally, a survey of

optimization strategies for system-level design in hybrid electric vehicles has been prepared in [7].

Timing and finance

The project has been running during the period 2015-01-01—2015-06-30.
The total project budget is SEK 1.180 million, all of which is funded by SHC.

Executors and collaboration

The project team was consisting of Bo Egardt (project manager), Nikolce Murgovski, Magnus Nilsson, and Lars Johannesson. The following persons were members of the reference group: Mikael Askerdal (AB Volvo), Mathias Björkman (Scania) and Anders Lasson (Volvo Cars).

As a part of this project, collaboration has been established with the Control Systems Technology section at Eindhoven University, during a scholar visit by Nikolce Murgovski for a two months period, in December 2014 – January 2015. The topics of common interest, concerning predictive cruise control and multivariable engine control, have also been discussed with DAF Trucks N.V.

Dissemination of Results

Project related results (mostly from earlier activities) on energy management were described in a seminar at Scania on 2015-02-03 and DAF Trucks N.V on 2015-01-26. There was also a presentation at the SHC event on 2015-06-04. In addition to the publications listed at the end, one more publication is in the planning phase.

As part of this project, SHC has sponsored the last part of Mitra Pourabdollah's PhD work on optimization of plug-in hybrid vehicles. During this time, one article was submitted for possible journal publication, see the publication list.

Papers and publications

[1] L. Johannesson, M. Nilsson, N. Murgovski: Look-ahead Vehicle Energy Management with Traffic Predictions. Submitted to E-COSM'15, IFAC Workshop on Engine and Powertrain Control, Simulation and Modeling, Columbus, Ohio.

[2] M. Nilsson, N. Murgovski, L. Johannesson: Combined platooning and energy management with high integrity. ICEEV 2015, 4th International Conference on Energy Efficient Vehicles, Dresden, Germany.

[3] M. Pourabdollah, N. Murgovski, A. Grauers, B. Egardt: Effect of Driving, Charging, and Pricing Scenarios on Optimal Component Sizing of a Plug-in Hybrid Vehicle. Submitted to *Control Engineering Practice*.

[4] N. Murgovski, S. Marinkov, D. Hilgersom, B. de Jagar, M. Steinbuch, J. Sjöberg: Powertrain sizing of electrically supercharged internal combustion engine vehicles. Submitted to IFAC Workshop on Engine and Powertrain Control, Simulation and Modeling (E-CoSM), Columbus, OH, USA, 2015.

[5] S. Marinkov, N. Murgovski, B. de Jager: Convex modeling and sizing of electrically supercharged internal combustion engine powertrain. Submitted to IEEE Transactions on Vehicular Technology.

[6] E. Feru, F. Willems, N. Murgovski, B. de Jager, M. Steinbuch: Supervisory control of a diesel engine with an electrified waste heat recovery system. Submitted to Control Engineering Practice.

[7] E. Silvas, T. Hofman, N. Murgovski, P. Etman, M. Steinbuch: Review of optimization strategies for system-level design in hybrid electric vehicles. Submitted to IEEE Transactions on Vehicular Technology.

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