Multiobjective Autonomous Driving

Sebastian Peitz and Michael Dellnitz

1 Executive summary

In a cooperative research project between the *Institute for Industrial Mathematics* at Paderborn University and *Hella KGaA Hueck & Co.*, algorithms were developed with which autonomously driving vehicles can be maneuvered in such a way that an optimal compromise between fast and energy efficient driving is obtained. Based on the passenger's preference, the weighting of these objectives can be adapted online.

2 Challenge overview

In order to enable a passenger to change his or her preferred style of autonomous driving online, knowledge of the entire set of optimal compromises between the concurrent objectives fast and energy efficient driving is desired. This requires a large number of function evaluations of the underlying mathematical vehicle model and therefore results in a significant, potentially prohibitive, computational effort. Since real time applicability is crucial in autonomous driving, new concepts need to be developed to drastically reduce the online computing time.

Sebastian Peitz
Institute for Industrial Mathematics, Warburger Str. 100, 33098 Paderborn e-mail: speitz@math.upb.de

Michael Dellnitz
Institute for Industrial Mathematics, Warburger Str. 100, 33098 Paderborn e-mail: dellnitz@upb.de

3 Implementation of the initiative

The technology network *it's OWL* – short for Intelligent Technical Systems OstWestfalenLippe – is a Leading-Edge Cluster funded by the Federal Ministry of Education and Research (BMBF). In the cluster 180 businesses, universities and other partners are working together in 46 research projects to develop intelligent technical systems. This specific project was carried out over a two-year period, where the electric vehicle model was developed by Hella and the real-time multiobjective optimal control algorithms were developed by the Institute for Industrial Mathematics.

4 The problem

Modeling the electric vehicle dynamics results in a coupled system of ordinary differential equations which cover the dynamics of both the electrical and the mechanical components of the vehicle. Evaluating the model for a given engine torque profile yields information about the distance driven (i.e. the final position) as well as the required amount of energy (i.e. the final battery state of charge). This can then be used in a multiobjective optimization algorithm to compute the set of engine torque profiles which lead to optimal compromises between these objectives (see the so-called Pareto front in Fig. 1). Therein, we also see that features of the track are captured within the optimization. For example, downhill sections lead to gaps in the Pareto front since, using recuperation, it is beneficial for both objectives to drive further downhill.

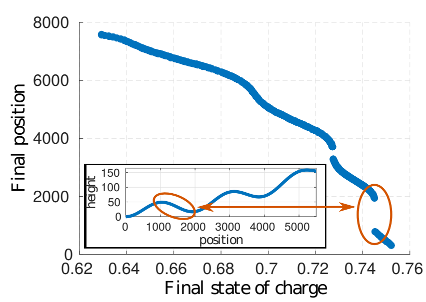

Fig. 1 Pareto front for the objectives maximize the final battery state of charge and maximize the final position.

Due to the large computational effort, the algorithm is split into an offline and an online phase. In the offline phase, a large number of multiobjective optimal control problems is solved for different initial and boundary conditions. In the online phase, the vehicle state is evaluated by sensor data and the corresponding solution set is selected from a library, which is significantly faster. According to the driver's preference, an optimal compromise is then chosen. This way, the passenger has the possibility to adapt the weighting of the objectives online and is therefore in the position to react on changing weather or traffic conditions or the remaining energy supply (see Fig. 2).

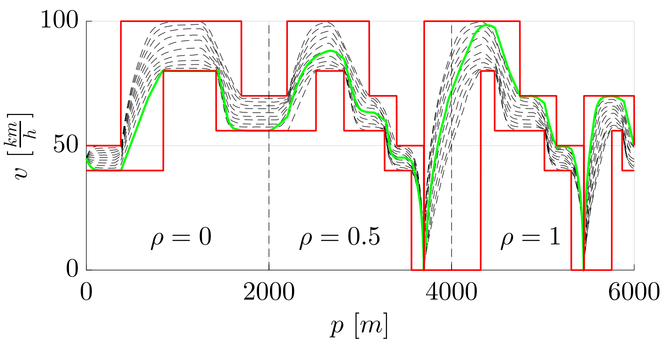

Fig. 2 Dynamic change in the objectives from energy efficient $\rho = 0$ to fast $\rho = 1$ (green line). The dashed lines correspond to constant weights and the red lines indicate the maximal and minimal velocity, respectively.

5 Results and achievements

A key result of the cooperation is the development of an adaptive automatic cruise control which is able to react on the environment in an intelligent way. The cooperation is on-going with the purpose to further improve the approach and guarantee stability and safety.

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