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Development of an intelligent cruise control using optimal control methods

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Abstract

In this contribution, the range extension problem of electric vehicles is addressed. To this aim, an intelligent cruise control is developed based on the formulation of an optimal control problem. Solutions of this optimal control problem are energy efficient accelerator pedal position profiles. They can be computed numerically by a direct optimal control method using sequential quadratic programming. The approach is applied to two different driving scenarios. The results show that the energy efficiency is increased by using optimal control for both an artificial and a realistic scenario.

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1. Introduction

Alternative drive technologies have gained more and more attention during the last years. This is mainly due to an increasing awareness of the impact of CO_2 emissions on climate change and the limitation of fossil fuels. Thus, research focuses, for instance, on electrically powered vehicles. Up to now, electric vehicles (EV) suffer from a

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severely reduced range compared to conventional internal combustion engine powered vehicles. Firstly, this is caused by the high battery cost and, secondly, by the limited lithium ion battery storage density. Therefore, strategies to increase the EV range without enlarging the battery play an important role for electromobility (cf. e.g. [1], [2]).

In this contribution, an „intelligent cruise control“ is designed to optimize the drivetrain power uptake by taking into account topographic information of a prescribed travel route. Standard cruise controls, which have been originally developed for fossil-fueled vehicles, have been adapted in a number of recent publications. In [3] and [4], for instance, *model predictive control* is used for reducing the fuel consumption of heavy diesel trucks on a known topography. It is shown that the variation of the vehicle's velocity – within certain limits – has the potential to decrease the overall energy consumption. Applying this method to EVs allows for larger travel distances and thereby overcomes range anxiety or increases the energy available for comfort functions such as air conditioning.

The task of minimizing the energy consumption on a given route can be formulated as an *optimal control problem* with the aim to determine the accelerator pedal position profile with respect to minimum battery depth of discharge (DOD). Different methods exist to solve such optimal control problems: *Indirect methods* make use of the necessary optimality conditions from the Pontryagin Maximum Principle while *direct methods* are based on a discretization by which the problem is transformed into a nonlinear constrained optimization problem (cf. Section 3 for details). An overview of appropriate control strategies in the case of hybrid electric vehicles can be found in [5]. Constraints on thermal conditions are additionally taken into account in [6].

Various strategies have also been considered for EVs. In [7], the solution of the optimal control problem is computed by *dynamic programming* techniques. This method allows the computation of control sequences for arbitrary starting points. However, due to the nature of this method, it is restricted to low-dimensional problems. For the solution of a higher dimensional problem, an indirect method exploiting the special geometric structure of the EV model is used in [8].

In contrast to that, we evaluate the use of a direct optimal control method in combination with black-box simulations for this application. In order to apply this method to the EV optimal control problem, we neglect the virtual driver (cf. Section 2) and directly compute an optimal solution for the accelerator pedal position profile by discretizing it with respect to time. In combination with the vehicle dynamics simulation model the optimal control problem is transformed into a nonlinear restricted optimization problem. This time discretized accelerator pedal position profile leads to a large number of optimization parameters. This optimization problem is solved using a standard sequential quadratic programming (SQP) method (cf. e.g. [9]). We then compute several solutions for different slope profiles and investigate the influence of different discretizations and initial guesses on the quality of the solution.

The remainder of this article is organized as follows: In Section 2, the simulation model of an EV is described. The direct numerical method which is used for the solution of the corresponding optimal control problem is described in Section 3. In Section 4, the specific optimal control problem based on the simulation model is formulated and solved by the direct method introduced before. Finally, a conclusion can be found in Section 5.