A Design Method of Nonlinear Real-Time Optimal Controllers to Save Energy for Hybrid Electric Vehicle and Plug-In Hybrid Electric Vehicle Powertrains

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論文題名　：A Design Method of Nonlinear Real-Time Optimal Controllers to Save Energy for Hybrid Electric Vehicle and Plug-In Hybrid Electric Vehicle Powertrains　（ハイブリッド電気自動車とプラグインハイブリッド電気自動車パワートレインの非線形実時間最適化省燃費コントローラの一設計法）

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論 文 内 容 の 要 旨

In recent years, more efficient and cleaner energy utilization technology has become a research hotspot due to the rising prices of fossil fuels and environmental problems. The problems have led to the development of hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). In this context, population of HEVs and PHEVs (referred as hybrid vehicles later) is growing. HEVs consist of the traditional internal combustion engine, the battery, and the motor/generator as their powertrains. The difference of HEVs and PHEVs is that PHEVs have an enlarged battery pack and can charge the battery using electricity from an electric grid with a plug. Hybrid vehicles can regenerate the dissipation kinematic energy during deceleration and use the redundancy that the internal combustion engine and the motor/generator can provide energy at the same time to save energy. A properly controlled hybrid vehicle having the redundancy can reduce fuel consumption compared with that using a conventional internal combustion engine vehicle (ICEV). However, the engine optimal operating point depends on the property of the engine, the surrounding traffic conditions, the road slopes till the destination, and so on which change every moment. Also, if the battery is operated beyond the battery state of charge limits, this will lead the battery degradation and affect the battery longevity. There are two kinds of conventional controllers for hybrid vehicles which are the rule-based controller and the feed forward type controller. The rule-based controller can keep the battery state of charge between the thresholds; however it cannot guarantee the optimality of fuel economy. The feed forward type controller optimizes the operating points of the powertrain given the driving profile. In this dissertation, the nonlinear real-time optimal controller is proposed to cope with the above difficulties.

The proposed method can optimize both the engine operating points and the driving profile simultaneously. Though the hybrid vehicle powertrain is nonlinear, the proposed nonlinear real-time optimal control approach can modify the optimal driving profile considering surrounding vehicle driving conditions every sampling interval. The 30%-50% of fuel economy improvements is realized by the proposed approach. This dissertation improves HEV/PHEV energy management research by adding three main novel contributions. First, using the HEV/PHEV property, the desired battery state of charge is designed according to the road slopes for better recuperation of free regenerative braking energy. Second, the battery state of charge at the instant of reaching the destination can be specified to utilize the remaining battery charge as a home power source. Third, the vehicle spacing is kept above the minimum value, and this gives the freedom of control for vehicle speed variety to get better fuel economy. The topic is addressed in three phases according to the model types.

First, the existing model of hybrid vehicles that models the dynamics of the battery is used to confirm the fuel economy improvements. Considering the HEV physical constraints: the battery state of charge bounds and the vehicle speed limit beforehand makes the optimization and the fuel improvements trustworthy. The desired battery charge/discharge profile is obtained using the proposed approach. The optimal power-split between the engine and the battery is obtained.

Second, the plant models of the battery, the engine, and the motor/generator are developed in this research. These models are proposed to optimize both the engine operating points and the driving profile considering the engine dynamics, the battery dynamics, and the vehicle dynamics with HEV physical constraints: the speed and torque limits of the engine and motor/generators.

Third, the proposed method is extended when the driving distance is unknown using the existing model of hybrid vehicles. There are two kinds of control strategies for PHEVs: charge depletion and all-electric charge depletion followed by charge sustenance. The fuel economy improvements for the PHEV are confirmed with driving distance uncertainty in reality using the proposed all-electric charge depletion followed by charge sustenance control method. The proposed controller can be constructed without the trip distance information which is required in the control method above.

In total, this dissertation proposed a nonlinear real-time optimal control algorithm for energy management in HEVs and PHEVs. The main contribution is a systematic real-time optimal control approach for energy management in HEVs and PHEVs using the information of future road loads. This systematic design process is useful for significant fuel economy improvements in the energy management control unit application without improvements of powertrain hardware. The conclusion is that the nonlinear real-time optimal control approach has effectiveness for the energy management problem of the HEV/PHEV system.