2022-01-1122 Published 30 Aug 2022

Shared Control Based Energy Management Strategy for Hybrid Electric Vehicle Taking into Account Demand Power Optimization

Tao Liu, Bingliang shi, and Laiqing Xie Vehicle Research Institute

Citation: Liu, T., shi, B., and Xie, L., "Shared Control Based Energy Management Strategy for Hybrid Electric Vehicle Taking into Account Demand Power Optimization," SAE Technical Paper 2022-01-1122, 2022, doi:10.4271/2022-01-1122.

Received: 01 May 2022 Revised: 01 May 2022 Accepted: 24 Jun 2022

Abstract

To further explore the potential of fuel economy for hybrid electric vehicle (HEV), a shared-control-based energy management strategy (SCEMS) with four modules of the human-vehicle closed-loop system, reference power calculation, driver power distribution, and shared control strategy is proposed. The SCEMS possesses three innovations. Firstly, the rational driver's power demand is considered to achieve optimal fuel consumption. Secondly, a dimensionality reduction strategy of two-dimension DP algorithm is proposed for online application. Finally, based on the shared control and the intelligent traffic system (ITS) a game mechanism between driver and controller is constructed to adapt to different driving styles and road conditions. In the human-vehicle closed-loop system, a model is built, combining the driver model with a longitudinal dynamic model, to optimize the power demand and power distribution. In the reference power calculation, the dynamic programming (DP) algorithm is utilized to produce the optimal power of a future forward road segment based on the ITS. The time complexity of DP algorithm is reduced by a state of charge (SOC) table looked up online derived from neural network and road condition identification. In the driver power distribution, the original demand power is assigned to the engine and motor. In the shared control strategy, two condition description equations are respectively constructed to indicate the fuel consumption rate of the engine and the efficiency of the motor, and then two adjustment curves are fitted to regulate the proportion of driver and controller to improve the power-wasting and ineffective behaviors. The problem of driving style and emergency road condition adaptation is settled depending on the cumulative-error-based weight adjustment strategy.

Introduction

Plug-in Hybrid Electric Vehicle (PHEV) can obtain electric energy from the external power grid through charging, and its strategy is to consume electricity to the lower limit within the determined range of travel, reduce part of the fuel consumption, and adjust the engine to work in the high-efficiency area. The EMS of PHEV is mainly divided into optimization-based strategy and rule-based strategy. With the development of new technologies such as the internet of vehicles, some new strategies have also emerged. Optimization-based EMS refers to strategies that use optimization algorithms to solve solutions, mainly including DP, PMP, and GT. C. Romaus et al. [1] have presented a strategy to control power distribution with DP based on consideration of traffic conditions and random effects of drivers. The rule-based energy management strategy has become the first choice for practical engineering applications due to its simple structure, small computational complexity, and low memory footprint, mainly including CDCD and NN. To overcome the shortcomings of NN, literature [2] has proposed a control rule to extract the optimal solution of multiple typical working conditions and a strategy of selecting corresponding rules based on working condition identification in the online application. With the rapid development of ITS centered on intelligent network technology, the traditional EMS has gained new vitality. Reference [3] has proposed a PHEV energy management system based on vehicle-vehicle, vehicle-road communication system, and cloud computing for vehicle speed prediction. For different application scenarios such as intersections, the author uses the obtained surrounding vehicle and traffic light information, combined with the car following model to predict the future speed of the vehicle. The prediction algorithm adopts an improved chain NN taking the prediction result of the previous step as one of the inputs of the next prediction, which is similar to the idea of a recursive network, and the prediction accuracy is greatly improved. Finally, according to the guidance of future road condition information, the equivalent factor of the ECMS strategy is adjusted in real-time. Compared with the traditional adaptive ECMS, the economy of this strategy is improved by about 5%. Ozatay E et al. [4] have proposed a cloud computing-based optimal vehicle speed assistance decision system for HEV. The

References

1. Romaus, C., Gathmann, K., and Bocker, J. "Optimal Energy Management for a Hybrid Energy Storage System For Electric Vehicles Based on Stochastic Dynamic Programming," *2010 IEEE Vehicle Power and Propulsion Conference* (2010): 1-6.
2. Tian, H., Ziwang, L., Wang, X., Zhang, X. et al., "A Length Ratio Based Neural Network Energy Management Strategy for Online Control of Plug-in Hybrid Electric City Bus," *Applied Energy* 177 (2016): 71-80.
3. Zhang, F., Xi, J., and Langari, R., "Real-Time Energy Management Strategy Based on Velocity Forecasts Using V2V and V2I Communications," *IEEE Transactions on Intelligent Transportation Systems* 18 (2017): 416-430.
4. Ozatay, E., Onori, S., Wollaeger, J., Özgüner, Ü. et al., "Cloud-Based Velocity Profile Optimization for Everyday Driving: A Dynamic-Programming-Based Solution," *IEEE Transactions on Intelligent Transportation Systems* 15 (2014): 2491-2505.
5. Liu, T., Lu, Z., and Tian, G. "Energetic Macroscopic Representation Based Energy Management Strategy for Hybrid Electric Vehicle Taking into Account Demand Power Optimization," 2017.
6. Mulder, M. and Abbink, D.A. "Correct and Faulty Driver Support from Shared Haptic Control During Evasive Maneuvers." *2011 IEEE International Conference on Systems, Man, and Cybernetics (2011)*: 1057-1062.
7. Zhu, D., Pritchard, E.G.D., Dadam, S.R., Kumar, V. et al., "Optimization of Rule-Based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming," *Combustion Engines* 184 (2021): 3-10.
8. Griffiths, P.G. and Gillespie, R.B., "Sharing Control Between Humans and Automation Using Haptic Interface: Primary and Secondary Task Performance Benefits," *Human Factors: The Journal of Human Factors and Ergonomics Society* 47 (2005): 574-590.
9. Abbink, D.A. and Mulder, M. "Neuromuscular Analysis as a Guideline in designing Shared Control," 2010.
10. Rossetter, E.J. and Christian Gerdes, J., "Lyapunov Based Performance Guarantees for the Potential Field Lane-keeping Assistance System," *Journal of Dynamic Systems Measurement and Control-transactions of The Asme* 128 (2006): 510-522.
11. Cole, D.J., Pick, A.J., and Odhams, A.M.C., "Predictive and Linear Quadratic Methods for Potential Application to Modelling Driver Steering Control," *Vehicle System Dynamics* 44 (2006): 259-284.
12. Li, R., Li, Y., Li, S.E., Burdet, E., and Cheng, B. "Indirect Shared Control of Highly Automated Vehicles for Cooperative Driving between Driver and Automation." ArXiv abs/1704.00866 (2017): n. pag.
13. Balomenos, T., Raouzaiou, A., Ioannou, S., Drosopoulos, A.I. et al., "Emotion Analysis in Man-Machine Interaction Systems," *MLMI* (2004).
14. Hoeger, R., Amditis, A.J., Kunert, M., Hoess, A. et al., "Highly Automated Vehicles for Intelligent Transport: Have-It Approach." (2008).
15. Nguyen, A.-T., Sentouh, C., and Popieul, J.-C., "Driver-Automation Cooperative Approach for Shared Steering Control Under Multiple System Constraints: Design and Experiments," *IEEE Transactions on Industrial Electronics* 64 (2017): 3819-3830.

Contact Information

Tao Liu
junjiaoliutao@163.com

Definitions/Abbreviations

PHEV - plug-in hybrid electric vehicle

SCEMS - shared-control-based energy management strategy

EMS - energy management strategy

ITS - intelligent traffic system

DP - dynamic programming

NN - neural network

SOC - state of charge

PMP - pontryagin's minimum principle

GT - game theory

CDCS - Charge-Depleting Charge-Sustaining

© 2022 SAE International. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE International.

Positions and opinions advanced in this work are those of the author(s) and not necessarily those of SAE International. Responsibility for the content of the work lies solely with the author(s).

ISSN 0148-7191