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Research progress and prospect of energy-saving optimal control for intelligent and connected electric vehicles

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Abstract: Modern communication and network technology are integrated to realize the exchange and sharing of intelligent information between vehicles, roads, people and clouds. It has the functions of complex environment perception, intelligent decision-making, collaborative control, etc., and can realize safe, efficient, comfortable and energy-saving driving, and finally realize a new generation of ICEV (Intelligent and Connected Electric Vehicles)operated instead of people. For ICEV, it is important to optimize the speed trajectory by using the information of the road ahead to realize the predictive energy-saving control, which will improve the economy of the vehicle. In order to fully understand the research progress of the optimal control of ICEV, the key issues of the optimal control of vehicle energy consumption and emissions based on the information of intelligent network are summarized. Finally, the future challenges in intelligent vehicle optimization are prospected, which provides a reference for further extensive research.

1. Introduction

With the continuous improvement of the coverage of intelligent transportation network and the efficiency of information acquisition, using the network of vehicles and infrastructure, vehicles and vehicles, vehicles and other objects (people, clouds, networks), we can obtain constantly changing navigation, high-precision maps and traffic environment information in real time, and comprehensively predict the impact of future traffic conditions on vehicle driving. The integration of modern communication and network technology can realize the exchange and sharing of intelligent information between vehicles, roads, people and clouds, and has the functions of complex environment perception, intelligent decision-making, collaborative control, etc., which can realize safe, efficient, comfortable and energy-saving driving, and finally realize a new generation of ICEV(Intelligent and Connected Electric Vehicles) operated instead of people [1].

In order to reduce energy consumption and emissions, automobile energy-saving technology has become an important way. Therefore, this paper aims at the frontier issues of intelligent energy saving and emission reduction of automobiles, focusing on economic driving, summarizes the key issues and main research status of intelligent energy saving optimization of ICEV, and finally summarizes the full text and introduces the challenges faced by current research.

2. Research progress of ICEV energy-saving optimal control

2.1. ICEV energy-saving assisted driving based on information interconnection

The energy consumption of ICEV during driving is influenced by many factors, such as driving speed, road slope, vehicle movement in front, traffic lights and so on. For ICEV, because of its limited driving distance, it is of positive significance to use vehicle-to-vehicle communication and vehicle-road communication technology to realize energy-saving auxiliary control of ICEV and improve its energy utilization rate.

At present, in the relevant research on energy-saving auxiliary control of ICEV, the main research idea is to optimize energy distribution and torque for ICEV on the premise that information such as traffic light timing, road gradient change or future speed change law of the vehicle is known all the time. The application scenario of the intelligent energy-saving control function of the EMU is shown in Figure 1 [2].

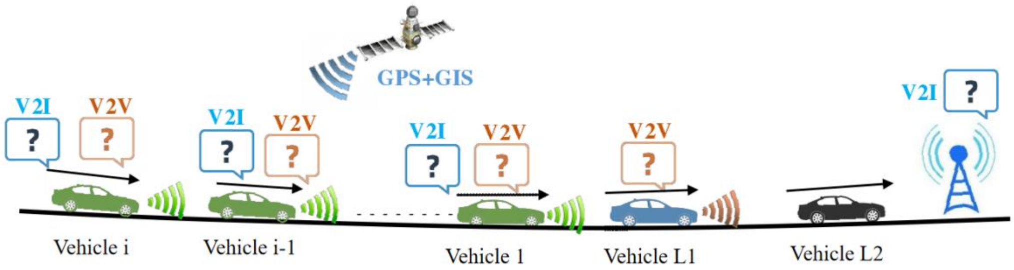

Figure 1: Schematic diagram of intelligent energy-saving control working condition of electric locomotive team

The ICEV numbered i, i-1,…, 1 together form an electric car team, and there are two front cars L1 and L2 in front of the team. Modeling the movement behavior of the lead car L1 and predicting its future movement, so as to ensure that more accurate future movement information of the vehicle L1 can be obtained in each control cycle of the electric vehicle fleet, and to reduce the overall energy consumption of the fleet.

In the research of document [3], the speed spectrum of the driving process is known before departure, and the self-propelled vehicle is controlled to follow the speed spectrum by MPC or DP, and at the same time, the multi-energy sources of the hybrid vehicle are coordinated, or the torque of the front and rear axle motors of the distributed ICEV is distributed to achieve the lowest energy consumption in the speed following process. In the study of reference [4], the microscopic and macroscopic traffic information of the road ahead is used to predict the traffic situation in front, so as to realize energy-saving assisted driving of vehicles. This kind of method introduces the motion information of the front vehicle into the energy-saving auxiliary control of the own vehicle, so that the own vehicle can reduce the driving energy consumption on the basis of keeping a reasonable relative distance from the front vehicle during the control process. This kind of research is often limited to traditional vehicles, and usually ignores the influence of road gradient on vehicle driving energy consumption.

In article [5], information is collected by using vehicle front radar, blind spot monitoring radar, lane-changing auxiliary camera and driver's head monitoring camera, and the information fragments of lane-changing actions are screened, and the relevant vector machine model is trained to predict the driver's lane-changing driving behavior in advance. In each control cycle of the vehicle, if we can have a clearer understanding of the movement behavior of the surrounding vehicles in the next few steps, it will effectively improve the control effect of the vehicle, avoid excessive acceleration and braking behavior, and effectively save driving energy.

With the development of vehicle intelligence and networking technology, some advanced sensors are gradually applied to vehicles as necessary components to sense the internal state information and external environment information of bicycles in real time. Literature [6] proposes that the mismatch of measured values caused by radar clutter should be considered while applying radar information, and puts forward a robust solution, so that information fusion and state estimation can still be carried out when there are abnormal clutter values.

2.2. ICEV predictive energy saving control

For ICEV, it is important to optimize the speed trajectory by using the road information in front to realize the predictive energy-saving control, which plays an important role in improving the economy of vehicles. The simplified relationship between motor efficiency and motor torque is obtained by fitting the experimental data in reference [7], which is used in wheel torque control distribution. Literature [8] studies the optimal distribution of wheel torque based on the motor loss model, and then optimizes the total torque demand and speed trajectory of the vehicle in each driving stage to improve the driving economy of the vehicle in urban traffic conditions.

In the above research, it is not clear about the influence of wheel torque distribution and speed optimization on the optimization results. Based on the longitudinal dynamic model of the vehicle and the energy efficiency model of the drive system, the vehicle speed trajectory optimization problem for energy saving can be described as an MPC problem. Then, the dynamic programming algorithm is used to solve the optimization result. In this way, an MPC problem in the prediction domain can be solved. The optimized speed trajectory obtained by predictive energy-saving control is accelerated in advance before starting uphill to avoid a sharp increase in driving torque. In the downhill process, gravity acceleration is reasonably used to reduce the energy loss caused by braking, while in the case of uniform speed, the torque will increase and decrease rapidly in the uphill and downhill processes, which will increase the energy consumption.

In the aspect of optimal control, reference [9] determines the power flow relationship of the energy management system of pure electric vehicles, introduces the power distribution coefficient of the energy management system, and designs a fuzzy optimal control strategy. Literature [10] establishes a mathematical model with vehicle energy consumption rate and acceleration time as objective functions, and designs an energy management optimization controller based on fuzzy logic. Due to different emphases, although the above-mentioned research on optimal control strategy has achieved certain research results in their respective research fields, it is still difficult to give full play to the advantages of energy consumption economy of electric vehicles because the control strategy does not comprehensively consider the influence of mileage, initial SOC of battery, driver's intention and cycle conditions. The relationship between energy management strategy and battery life is a multi-factor coupling relationship, and they influence each other. At present, most energy management strategies are only formulated for specific working conditions, and few factors are considered, which cannot give full play to the energy-saving potential of electric vehicles. Literature [11] analyzes the relationship between the characteristic parameters of driving conditions, the dynamic control method of electric energy and the electric energy consumption of ICEV through the experiment of ICEV.

The battery SOC is affected by various nonlinear factors such as temperature, internal resistance, charge-discharge rate, etc. Its internal chemical reaction is complex, and the SOC cannot be measured directly. The battery SOC can only be estimated by measuring related external characteristics and algorithms. Scholars at home and abroad have studied the estimation methods of battery SOC and put forward many estimation algorithms. Literature [12] proposes a driving range estimation model based on energy state estimation of power battery and vehicle energy consumption prediction. Battery energy state estimation uses battery state model to estimate the remaining available energy of the battery, and analyzes the influence of different factors. Using the test data of pure electric vehicles, the vehicle energy consumption parameters are identified based on recursive least square method, and the vehicle energy consumption is predicted in combination with driving conditions, and the driving range is calculated. Literature [13] comprehensively considers the road terrain prediction information and motor efficiency, and optimizes the driving torque of front and rear wheels at the same time to minimize the energy consumption of vehicles on a given path.

2.3. ICEV collaborative energy-saving control

Realistic intelligent transportation is a complex system composed of traffic flow, road information and cloud composed of a large number of drivers and vehicles. In order to give full play to its advantages of high sensitivity in the transportation system, autonomous vehicles must rely on collaborative intelligent control technology to improve the efficiency and ability of collaborative energy saving among multi-agents [14]. Among all the control schemes, the rule-based control scheme has the advantages of minimum calculation and best real-time performance in practical experimental applications.

Reference [15] puts forward a vehicle acceleration suggestion tool. When the driver tries to accelerate quickly, the tool reduces the excessive acceleration by increasing the resistance of the accelerator pedal, so as to improve the fuel economy and emission performance, which is verified by the tests of four postal vehicles in different driving modes. Literature [16] based on machine learning, the problem of "outlier detection" is solved by using SVM square method, and the fitting method of specific kernel function of SVM is proposed to improve the robustness and repeatability of vehicle turning speed model. In order to save energy in coordination between vehicles, vehicles can exchange detailed motion state information, such as current position, speed and acceleration, through real-time communication, so as to adaptively adjust the motion mode conversion between multiple vehicles and improve the economy and safety under complex environmental conditions [17].

A large number of user data, vehicle data and environmental data can be transmitted to the cloud for storage, management and analysis through the network, forming a cloud data center integrating multi-source data, generating personalized customization and intelligent adaptation of human-machine interface, and promoting the transformation of automobile industry to the direction of "big data, interconnection and platform" of intelligent manufacturing. In the car, gaze recognition is applied to interactive tasks such as pointing and selection, which can improve the interaction rate, reduce the cognitive load and operation burden, and can also serve the elderly, the disabled and other people with weak physical functions.

Reference [18] introduces Gaussian process regression model to predict the future acceleration of the preceding vehicle, and solves the constrained rolling time domain optimization problem online by changing the cost function. Literature [19] deals with different traffic conditions by dynamically updating safety model parameters, and designs a double reinforcement learning method to maximize traffic efficiency, safety and comfort. Existing research shows that there is an interaction between traffic signal setting and vehicle emissions and traffic conditions [20]. Vehicles can obtain real-time information such as traffic light timing, length of speed-limited road section and distance from congested road section through networking with basic transportation facilities to optimize vehicle operation and improve fuel consumption and emission performance.

3. Development prospect

Real-time performance of information data processing and control algorithm. In the Internet of Vehicles environment, in addition to its own motion information data, vehicles also need to collect and process a large number of external environmental data such as radars and cameras and massive information stored in high-precision maps. The information sharing between "vehicle-road-electricity" can provide more useful data for vehicles, thus helping vehicles to decide the motion state that adapts to the current working conditions, and the optimization of energy distribution can further improve the electricity utilization efficiency of intelligent heavy commercial vehicles under the electrified road environment.

From the above research, it can be seen that it is the mainstream direction to carry out more detailed and comprehensive battery testing, improve measurement accuracy and establish more accurate battery characteristic model to meet the needs of battery SOC estimation. Realizing parameter adaptation in the estimation process is an effective means to improve the accuracy of estimation and identification, especially when there are system model errors and parameter perturbation, how to improve the estimation accuracy of the algorithm is the key problem to be solved in the next step. The future research will focus on the shift process, mode conversion, engine idle stop and the bench test and real vehicle test of the algorithm in the car-following process.

4. Conclusion

In order to reduce energy consumption and emissions, ICEV has become an important way to save energy on automobiles. For ICEV, because of its limited driving distance, it is of positive significance to use vehicle-to-vehicle communication and vehicle-road communication technology to realize energy-saving auxiliary control of ICEV and improve its energy utilization rate. At present, in the relevant research on energy-saving auxiliary control of ICEV, the main research idea is to optimize energy distribution and torque for ICEV on the premise that information such as traffic light timing, road gradient change or future speed change law of the vehicle is known all the time. For ICEV, it is important to optimize the speed trajectory by using the road information in front to realize the predictive energy-saving control, which plays an important role in improving the economy of vehicles. Among all the control schemes, the rule-based control scheme has the advantages of minimum calculation and best real-time performance in practical experimental applications.

References

[1] Dongxin, L., Qiqige, W., Wenbo, C., Huilong, Y., & Xiaoping, D. (2021). A priority tree based coordination method for intelligent and connected vehicles at unsignalized intersections. IET intelligent transport systems, 2021(8), 15.

[2] Zhang, X., Cheng, Z., Ma, J., Huang, S., Lewis, F. L., & Lee, T. H. (2022). Semi-definite relaxation-based admm for cooperative planning and control of connected autonomous vehicles. IEEE transactions on intelligent transportation systems,2022(7), 23.

[3] Mahmoud, A., Noureldin, A., & Hassanein, H. S. (2019). Integrated positioning for connected vehicles. IEEE Transactions on Intelligent Transportation Systems, 2019(99), 1-13.

[4] Jing, S., Hui, F., Zhao, X., Rios-Torres, J., & Khattak, A. J. (2019). Cooperative game approach to optimal merging sequence and on-ramp merging control of connected and automated vehicles. IEEE Transactions on Intelligent Transportation Systems, 2019(99), 1-11.

[5] Li, S., Shu, K., Chen, C., & Cao, D. (2021). Planning and decision-making for connected autonomous vehicles at road intersections: a review. Chinese Journal of Mechanical Engineering, 34(1), 1-18.

[6] Lijun, Q., Lihong, Q., Peng, C., Zoleikha, A., & Pierluigi, P. (2017). Fuel efficient model predictive control strategies for a group of connected vehicles incorporating vertical vibration. Science China Technological Sciences, 2017(11), 140-154.

[7] Abousleiman, R., & Rawashdeh, O. (2014). Energy efficient routing for electric vehicles using particle swarm

optimization. Sae Technical Papers, 1(1), 148-155.
[8] Wang, Y., Jiang, J., & Mu, T. (2013). Context-aware and energy-driven route optimization for fully electric vehicles via crowdsourcing. IEEE Transactions on Intelligent Transportation Systems, 14(3), 1331-1345.
[9] Nandi, A. K., Chakraborty, D., & Vaz, W. (2015). Design of a comfortable optimal driving strategy for electric vehicles using multi-objective optimization. Journal of Power Sources, 283(1), 1-18.
[10] Dong, H., Zhuang, W., Chen, B., Wang, Y., Lu, Y., & Liu, Y l. (2022). A comparative study of energy-efficient driving strategy for connected internal combustion engine and electric vehicles at signalized intersections. Applied Energy, 310, (10), 24.
[11] Komiyama, R., & Fujii, Y. (2013). Analysis of energy saving and environmental characteristics of electric vehicle in regionally-disaggregated world energy model. Electrical Engineering in Japan, 186(4), 20-36.
[12] Guo, H., He, H., & Sun, F. (2013). A combined cooperative braking model with a predictive control strategy in an electric vehicle. Energies, 6(12), 6455-6475.
[13] Hongwei, Zhang, W., Chen, Z., Shang, Z., Xu, Z., & Gao, Y l. (2020). Optimum driving system design for dual-motor pure electric vehicles. Journal of Beijing Institute of Technology, 29,106(04), 161-171.
[14] Xie, L., Luo, Y., Li, S., & Li, K. (2018). Coordinated control for adaptive cruise control system of distributed drive electric vehicles. Qiche Gongcheng/Automotive Engineering, 40(6), 652-658.
[15] Chasse, A., & Sciarretta, A. (2011). Supervisory control of hybrid powertrains: an experimental benchmark of offline optimization and online energy management. Control Engineering Practice, 19(11), 1253-1265.
[16] Salehi, J., Namvar, A., & Gazijahani, F. S. (2019). Scenario-based co-optimization of neighboring multi carrier smart buildings under demand response exchange. Journal of Cleaner Production, 235(20), 1483-1498.
[17] Zeng, X., Qian, Q., Chen, H., Song, D., & Li, G. (2021). A unified quantitative analysis of fuel economy for hybrid electric vehicles based on energy flow. Journal of Cleaner Production, 292(7411), 126040.
[18] Ubukata, N., Fukasawa, S., Yamashita, Y., & Kaneko, K. (2012). Approach to the optimal energy-saving system for railway vehicles. Japanese Railway Engineering, 52(3), 51.
[19] Chen, Z., Liu, W., Yang, Y., & Chen, W. (2015). Online energy management of plug-in hybrid electric vehicles for prolongation of all-electric range based on dynamic programming. Mathematical Problems in Engineering, 2015, (17)1-11.
[20] Wang, H., Jiang, Z., Wang, Y., Zhang, H., & Wang, Y. (2018). A two-stage optimization method for energy-saving flexible job-shop scheduling based on energy dynamic characterization. Journal of Cleaner Production, 188(1), 575-588.