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「課程博士用」

学 位 論 文 の 要 旨

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学位論文題目	Research on key issues of health evaluation based on data-driven method for lithium-ion batteries（データ駆動法を用いた電池健全性評価に関する研究）		

学位論文要旨

In recent years, to resolve the global energy crisis and environmental pollution problems, major economies and automobile manufacturers in the world have strengthened the research and development of electric vehicles. As one of the most important systems of electric vehicles, battery management system which ensures the accurate estimation of the key states of traction batteries is the key to formulate an efficient energy management strategy, to extend the cycle life of the battery pack, as well as to achieve the safe and reliable operation of the batteries. The aging process of lithium-ion batteries is a dynamic coupling process affected by various factors, such as temperature, current rate and so on. The internal aging mechanism is very complex and the electrochemical parameters such as the property of battery materials are not easy to be obtained, which greatly increases the difficulty of establishing the mechanism model. To improve the state of health (SOH) estimation accuracy for lithium-ion batteries, the following researches based on the data-driven methods have been carried out in this dissertation.

1. **Analysis and test of the aging characteristics of lithium-ion batteries.** Given the influence of different environmental factors on battery aging, a battery aging test platform is built. A lithium-ion battery aging test procedure is designed, including aging tests at different ambient temperatures, different charging rates, and different depths of discharge. Based on the battery cycle aging test and the battery calendar aging test, statistical analysis and comparative research on the aging characteristics of lithium-ion batteries are carried out. Two empirical aging models are constructed to calculate the capacity loss of the battery.
2. **Estimation of the SOH of lithium-ion battery cells based on the improved Gaussian Process Regression (GPR) model.** The single kernel function based on the GPR model is not accurate in estimating the SOH of lithium-ion battery so that it cannot accurately capture the phenomenon of overall capacity decay and local capacity recovery. Herein, a method for estimating the SOH of lithium-ion batteries based on the modified GPR combined with charging and discharging features is proposed. First, the changes in battery voltage and temperature curves among different aging cycles are analyzed in details, and health indicators (HIs) that can effectively represent the health status of the battery are proposed. Then, the Pearson correlation analysis method is used to quantify the correlation between the HIs and SOH, and three HIs with strong correlation are employed in this study. Next, a novel compound kernel function is proposed for the battery SOH estimation, and different pairs of mean function and kernel function chosen from four

mean functions and sixteen kernel functions are used to construct the GPR models, and their estimation accuracy is compared subsequently. Finally, four different batteries with various initial health conditions from the NASA battery dataset are used to verify the performance of the proposed method. Experiments show that its estimated mean-absolute-error (MAE) and root-mean-square-error (RMSE) are only 1.7%, and 2.41%, respectively. The results show that compared with a single kernel function, the GPR model based on a composite kernel function is more suitable for capturing the battery aging characteristics of various trends and can achieve accurate estimation of the battery SOH.

3. **Battery pack health estimation based on early data.** For the estimation of the SOH of the battery pack, it takes a lot of time and economic cost to complete the full-life aging test of the battery pack. Aiming at the solving above problems, a method for predicting the future health of the battery pack is proposed, which involves the aging data of the battery cells over their entire life cycles and the early cycling data of the battery pack. Firstly, the HIs are extracted from the experimental data, and high correlations between the extracted HIs and the capacity are verified by the Pearson correlation analysis method. To predict the future health of the battery pack based on the HIs, degradation models of HIs are constructed by using an exponential function, long short-term memory network, and their weighted fusion. The future HIs of the battery pack are predicted according to the fusion degradation model. Then, based on the GPR algorithm and the battery pack data, a data-driven model is constructed to predict the health of the battery pack. Finally, the proposed method is validated by a series-connected battery pack with fifteen 100 Ah lithium iron phosphate battery cells. The MAE and RMSE of the health prediction of the battery pack are 7.17% and 7.81%, respectively, indicating that the proposed method has satisfactory accuracy. The results show that compared with the single feature decay model, the fusion feature decay model can predict the future HIs of battery pack with more accuracy, which contribute to the satisfactory prediction accuracy of battery pack health based on the GPR model.

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