VIETNAM NATIONAL UNIVERSITY – HCMC	SOCIALIST REPUBLIC OF VIETNAM
HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY	INDEPENDENCE – LIBERTY – HAPPINESS

DISSERTATION INFORMATION

Title: **TOWARD MULTIVARIATE DEEP LEARNING MODELS FOR LITHIUM-ION BATTERY STATE-OF-HEALTH PREDICTION**

Major: **COMPUTER SCIENCE**

Major code: **9480101**

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CONTENT

From statistical data, it is evident that practical applications built on 5G infrastructure, along with support Big Data and Edge Computing, have become increasingly popular nowadays. These factors significantly contribute to the operation of smart cities, allowing the transmission of a massive amount of information with very low latency. However, a major challenge of these technologies is the accompanying major increase in energy consumption. For 5G, high-speed transmission and large data traffic have caused energy demands to peaks, rising by more than 68% compared to traditional consumption levels, thus putting significant pressure on the power supply system. To address this issue, AC Main Modernization to modernize the power supply system is essential. An effective solution is to integrate Lithium-ion batteries (LIB) with smart energy, which are currently applied in over 90% of energy assurance systems for 5G. The use of LIB requires continuous, accurate monitoring of battery health and forecasting its future condition. This is the motivation for research on battery capacity forecasting, specifically the State-of-Health (SOH) index of LIB, which is the focus of this dissertation.

For LIB, the SoH of the battery tends to degrade over its life-time cycles. Charging the battery follows a common procedure known as CC-CV (Constant Current – Constant Voltage), which is applied to most LIBs and is the process used in the datasets presented in this dissertation. In this procedure, the charging process is standardized by stages, while the discharging process is allowed to vary freely according to application demands. Storing and analyzing battery cycle data helps evaluate the current health and predict the future condition of LIBs. From the data analysis, it can be observed that the battery SoH capacity of the cells in widely-used datasets, such as NASA and CALCE ones, tends to decline. Moreover, distinctive peaks also appear in the cycles of individual cells. The dissertation aims to predict the future capacity values based on past and present data. Additionally, the predicted values must be accurate, stable, and reliable. Furthermore, training time and memory usage need to be optimized. Addressing all these requirements constitutes the central research problems to be solved bellow.

- **[Research Question 1]**: Has there been a comprehensive survey on the problem of forecasting the capacity of LIBs, particularly examining modern deep learning methods applied to this problem?
- **[Research Question 2]**: Given the complex and unpredictable nature of battery data, along with the rapid development of deep learning models in other domains, it is essential to extract data both cycle-wise and channel-wise to feed into an advanced deep learning model for improved performance. Can this requirement be fulfilled?
- **[Research Question 3]**: Attributes within a battery cycle, collectively referred to as on-cycle attributes, have been mentioned in [**Research Question 2**]. However, attributes extracted from multiple cycles (off-cycle attributes) have not yet been leveraged. A clear example is the information known as relaxation effect between two cycles. Is there a way to leverage these attributes in models to improve forecasting performance with battery data that exhibits distinct peaks?

The objective of this dissertation is to address these research questions through proposed improvements and supporting experimental results. The dissertation will outline the approach to resolving each of the above questions in the main chapters, corresponding to the proposed models and experimental findings. Each chapter will proceed as follows: analysis of the research question, assessment of related studies, identification of limitations that can be improved, proposal of deep learning models to overcome those limitations, presentation of relevant experimental results, and finally, discussion and evaluation of the outcomes corresponding to each model. The dissertation's contributions are closely tied to answering the three research questions, including:

- The dissertation emphasizes the necessity of a comprehensive survey for this research problem to provide an overall view of the methods used, challenges encountered, and potential solutions, as well as to identify future research directions. This in-depth analysis is proposed to address [**Research Question 1].**

- The dissertation proposes several improvements in channel-wise and cycle-wise data extraction for LIBs, enhancing the accuracy of model training and capacity prediction. Additionally, leveraging the success of modern models such as Self-Attention with Fixed-point Positional Encoding, Transformer, and Graph Convolutional Networks, the dissertation incrementally applies these models to the problem, achieving promising experimental results. This contribution addresses **[Research Question 2]** and forms the basis for relevant publications presented in the dissertation.

- The dissertation recognizes the importance of off-cycle information alongside on-cycle data. Consequently, it analyzes and identifies the intrinsic characteristics of the data, introducing relaxation-effect information to significantly improve capacity prediction quality, thereby addressing **[Research Question 3]**. The related publications achieved through this improvement are also discussed in the dissertation.

The dissertation fulfills the key contributions set out in its objectives, corresponding to the three initial research questions. Experimental results demonstrate that the research directions and proposals are effective, as evidenced by the publications. The approach proposed in the dissertation can be considered suitable not only for the specific problem of LIB capacity prediction but also for similar time-series forecasting problems generally.

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