A Review on Real Driving Cycle-Based State of Charge Prediction for EV Batteries

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Abstract. Research on performance of Electric Vehicle is very important, especially in driving range of a Battery Electric Vehicle (BEV) that requires precise State of Charge (SoC) predictions. The battery SoC is an important parameter that reflects the performance of the battery. Meanwhile, the battery has varying time properties depending on real conditions when driving. It has a logical relationship in a strong non-linear form that makes it very complex. Therefore, SoC prediction based on the Real Driving Cycle (RDC) can accurately protect the battery, save energy, increase battery life, prevent overcharging or discharging, and also enable applications to make rational control strategies to achieve goals with a certain range. This paper provides a literature review of various papers that are relevant and related to SoC prediction method for BEVs based on RDC. This paper summarizes the approaches used in Li-ion battery SoC prediction. Three approaches are classified accordingly, i.e. simulation approach, data-driven approach and model-based approach. The results achieved imply that data-driven models, especially machine learning methods have the best accuracy. Based on the assessment of the various SOC prediction methods reviewed, the key issues and direction of developing SOC prediction in the future trend are also discussed.

Keywords: Real Driving, Charge Prediction, EV Batteries.

1 Introduction

The world is experiencing global warming caused by the Greenhouse Effect. One of the biggest contributors is exhaust gas from vehicles. Hence, electric vehicles are here to solve this problem. In terms of the development of Indonesian people's interest in battery-powered electric vehicles, it is in the past year that the sales rate of electric vehicles has increased exponentially [1]. Although electric vehicles have great potential, there are now concerns about the range of electric vehicle users. To reduce range anxiety, accurate estimation of EV energy consumption is required so that from a given

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battery State of Charge (SOC), the remaining distance can be estimated under conditions where the road network and driving conditions provide a complex environment [2].

As shown in Fig.1, that there are various factors affecting EV Range, including SoC, SoH, Trip Pattern, BMS, Traffic flow, External environment, Driving behavior, EV dynamic performance and Internal environment. Among the various influencing factors, SoC has the highest absolute value of the simple correlation coefficient. This means that SoC has a significant linear relationship with driving mileage [3].

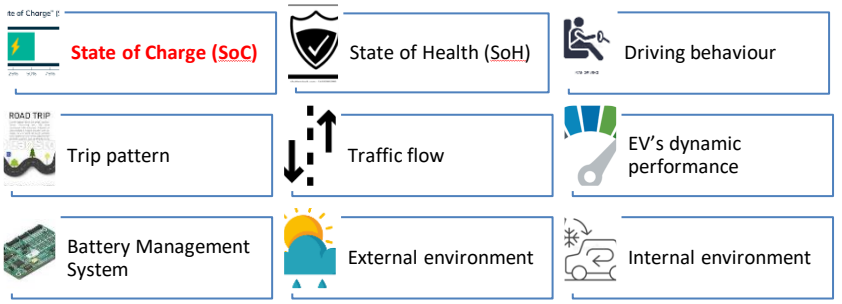

Fig. 1. Influence Factors of EV Range

As depicted in Fig. 2 that Drive cycle, Road Conditions, Environmental Conditions, Charging Pattern, driving habit., are parameters that can change or become variables in the prediction of SoC in RDC conditions.

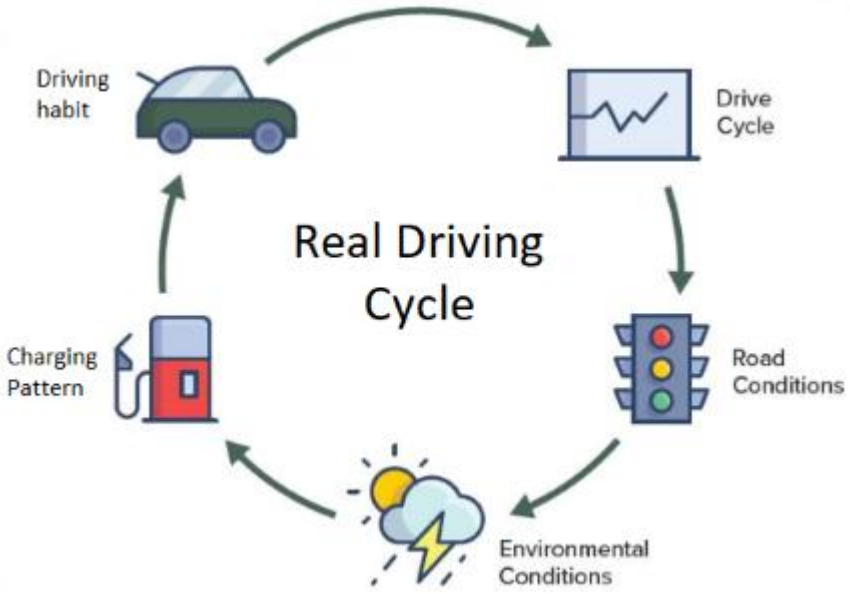

Fig. 2. Real Driving Cycle Based SoC Estimation

2 Method

2.1 Screening the Relevant Literatures

In this paper, the authors would like to present the results of a review of various papers relevant to SoC and energy consumption based on the real driving cycle. As presented in Fig. 3 is a methodology for screening the relevant literature search. Initially, six thousand papers were filtered, then filtered in several stages until 27 papers were selected.

Fig. 3. The Screening Methodology

3 Result and Discussion

In Fig. 4 presented on the left, is the distribution of publication times of the 27 relevant papers each year. This graph shows that it has only been around a decade since this research has only been discussed by researchers, so it is still rare, but over time there are more and more papers discussing this topic. The graph on the right is a graph of the distribution of the authors' country of origin, where the number of authors from America and China outperforms those from other countries.

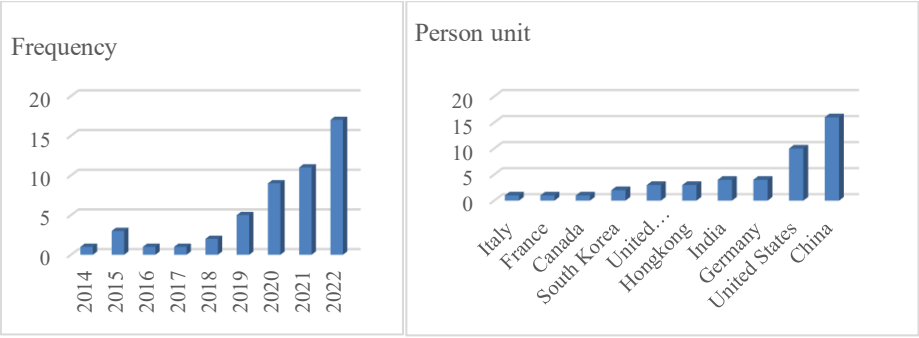

Fig. 4. Statistics Data of Relevant Papers: (left: Time Distribution of the 27 Relevant Papers in Every Years), (right: Author's Country of Origin)

Fig. 5 presents a graph of the distribution of journal sources. Most of the papers were obtained from SAE publishers. This publisher is indeed a target for researchers to publish research related to the EV range because it is exclusive, it is rare for universities to subscribe to this publisher so that in general it is rather difficult for researchers to access these papers.

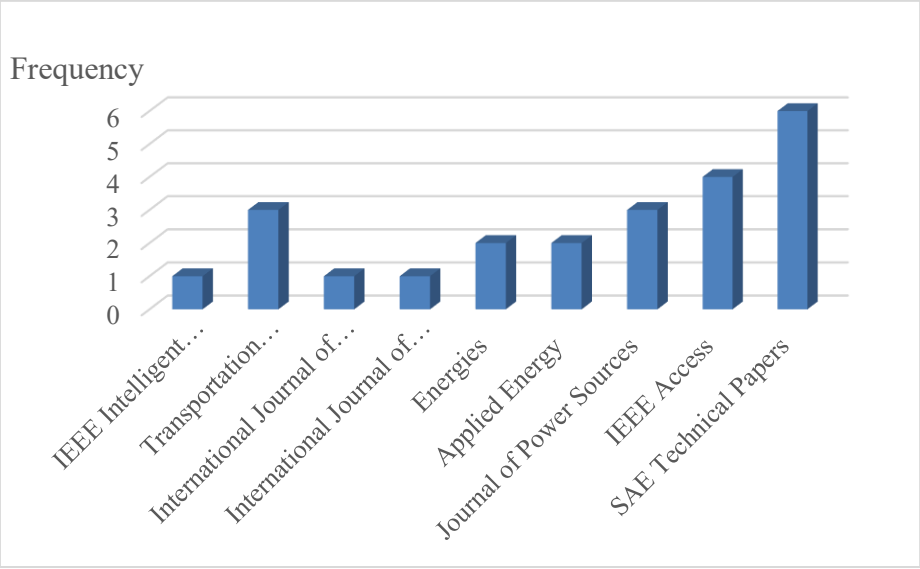

Fig. 5. Journal Source Distribution

Based on the results of reviews on previous relevant papers, the determination of parameters in the Real Driving Cycle can be presented in the following hierarchy. Parameters that are frequently used can be categorized into 3 aspects, namely external conditions, internal battery, and driving behaviour or auxiliary load.

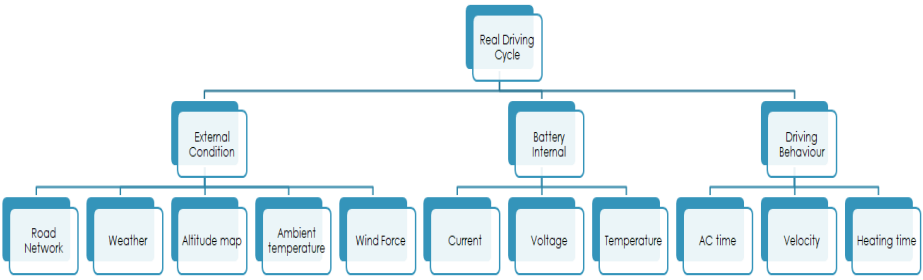

Fig. 6. Hierarchy of Determining Parameters in Real Driving Cycle

Therefore, in accordance with Fig. 6, the author can present a summary of the combination of parameters in the EV range and SoC in the Real Driving Cycle in Table 1.

As can be seen in the method column, in general there are method approaches used in RDC conditions, i.e., Simulation, Model-Based, Data-Driven.

Table 1. Combinations of Determining Factors in Real Driving Cycle

Author	Year	Parameters											Method
		External Condition					Battery Internal			Driving behaviour/ auxiliary load			
		RN/TF	W	Al/TM	Am/RT	WF	Cu	Volt	Temp	AC	V/S	HT	
Cauwer, dkk [4]	2017	√	√	√	√	-	√	√	-	√	√	-	Neural Network
Hong, dkk [5]	2021	√	-	√	√	-	√	√	√	√	√	-	Recurrent Neural Network
Sun, dkk [3]	2019	√	√	-	-	-	√	√	√	√	√	-	Gradient Boosting Decision Tree
Liu, dkk [6]	2018	√	√	√	√	-	-	-	-	√	√	√	Regression
Yavasoglu, dkk [7]	2019	√	√	-	√	-	-	√	√	√	√	√	Decision Tree
Ahmed, dkk [8]	2022	√	√	√	-	-	√	√	-	-	√	-	Regression
Hariharan, dkk [9]	2022	√	√	√	√	-	-	-	-	√	√	√	Simulation
Straub, dkk [10]	2020	√	√	√	√	√	-	√	-	-	√	-	Integral Method
El Din, dkk [11]	2018	-	-	-	-	-	√	√	√	-	-	-	Extended Kalman Filter
Szumska, dkk [12]	2021	√	√	√	√	√	√	√	-	√	√	√	Simulation
Zhao, dkk [13]	2020	√	-	-	√	-	√	√	√	√	√	-	XGBoost & LightGBM
Baek, dkk [14]	2019	√	√	√	√	-	√	√	-	-	√	-	Simulation

As shown in Table 1, relevant research that uses the data driven method comes from research by Cauwer, et al [4], Hong, et al [5], Sun, et al [3], Liu, et al [6], Yavasoglu, et al [7], Ahmed, et al [8], and Zhao, et al [13]. Then research using the simulation method was carried out by Hariharan, et al [9], Szumska, et al [12], and Baek, et al [14]. While the rest use the model-based method carried out by Straub, et al [10], and El Din, et al [11]. The majority of relevant recent research uses a data-driven approach and develops it by combining it with a simulation approach or a model-based approach. Because the data driven approach has shown better performance and high accuracy in predicting the EV range and SoC.

4 Conclusion

In general, researches of the approaches used in RDC are Simulation, Model-Based, Data-Driven. Parameters that are often used in RDC research are categorized into 3

aspects, i.e., external conditions, internal battery, and driving behavior. The author recommends for future research to combine the two approaches in conducting research.

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