Measurement 128 (2018) 197–203

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Residual range estimation for battery electric vehicle based on radial basis function neural network

Jun Bi[a,b,1], Yongxing Wang[a,*], Sai Shao[a,b], Yang Cheng[c]

[a] School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
[b] MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing 100044, China
[c] Department of Civil and Environmental Engineering, University of Wisconsin-Madison, Madison 53706, WI, USA

ARTICLE INFO

Keywords:
Residual range
Battery electric vehicle
RBF neural network
Estimation
Range anxiety

ABSTRACT

The accurate residual range estimation of a battery electric vehicle (BEV) can alleviate the driver's range anxiety and improve driving safety. In this study, the residual range estimation is considered a nonlinear system involving battery factors and a variety of vehicle working status factors. Given that the radial basis function neural network (RBF NN) performs well in approximating nonlinear systems, this study proposes a RBF NN method to estimate the residual range of BEV. The contribution analysis method is used to simplify the input layer of RBF NN and enhance the real-time performance of estimation. Then, the residual range is estimated by RBF NN using historical data newly collected at a fixed time in current discharge process. Some experimental data are from operational BEVs in Beijing, China. Experimental results of different types demonstrate that all errors are comparatively small and within the engineering limit.

1. Introduction

To reduce the fuel costs and pollution and to save the petrochemical energy, battery electric vehicle (BEV) which derives power from onboard electrical batteries has been utilised. BEV entirely converts chemical energy to electricity stored in rechargeable battery packs instead of fossil fuel in the conventional vehicles. However, BEV has fewer driving range in comparison with the hybrid electric vehicle (HEV). Therefore, during the trip, the driver tends to extend the range anxiety which is considered to be one of the major obstacles in the BEV penetration. The residual range is the distance that one BEV can continually run under present residual battery energy and vehicle working status. Then, the odometers in the BEVs can only display the travelled range rather than the residual range. Several studies for the residual range estimation of electric vehicle (EV) exist to [1] describe an electrochemical model built to calculate the residual capacity of a battery and then estimate the driving range of EV considering the driving style; Ref. [2] present the impact of driver behaviour on the range of EV which found that the range prediction can considerably vary by the impact of driving styles; considering to external influences and aging, Ref. [3] propose a model-based identification method to predict electric driving range for online parameter calibration; Ref. [4] estimate how much range can satisfy the drivers' daily need by analysing a large collection of driving data such as daily driving distance and maximum daily travel distance; Ref. [5] apply the machine learning methodology to estimate the residual capacity of a battery and then determine the corresponding range (a genetic algorithm-based clustering technique is used to learn the model parameters); Ref. [6] propose a reduced electrochemical model to realise the efficient condition monitoring for batteries (the driving range of EVs would be determined on the basis of the battery state of charge (SOC) that is obtained by using the model; and Ref. [7] conduct a survey on the several types of batteries and their management needs. The batteries that are often used in EVs and their discharge characteristics were analysed. Results can be used to estimate the driving range of EVs. However, the nonlinearity of the driving range of BEVs was not considered in these previous studies. Practically, the driving range of BEVs is influenced by several factors, such as speed, battery voltage and battery temperature. The complicated nonlinear relationships between the driving range and factors exist. Therefore, estimating the residual range of BEVs by using the conventional modelling methods is different.

To realise the accurate estimation for the residual range of BEVs, the nonlinearity of the driving range and its impacting factors need to be considered. An effective method to address such problems is the neural network methods, which has a strong nonlinear characteristic [8]. In recent years, some neural network methods have been introduced to

* Corresponding author.
E-mail addresses: bilinghc@163.com (J. Bi), yx_wang@bjtu.edu.cn (Y. Wang), cheng8@wisc.edu (Y. Cheng).
[1] Address: Beijing Jiaotong University, School of Traffic and Transportation, NO. 3 Shangyuancun Street, Beijing 100044, China.

https://doi.org/10.1016/j.measurement.2018.06.054
Received 31 December 2016; Received in revised form 21 April 2018; Accepted 25 June 2018
Available online 25 June 2018

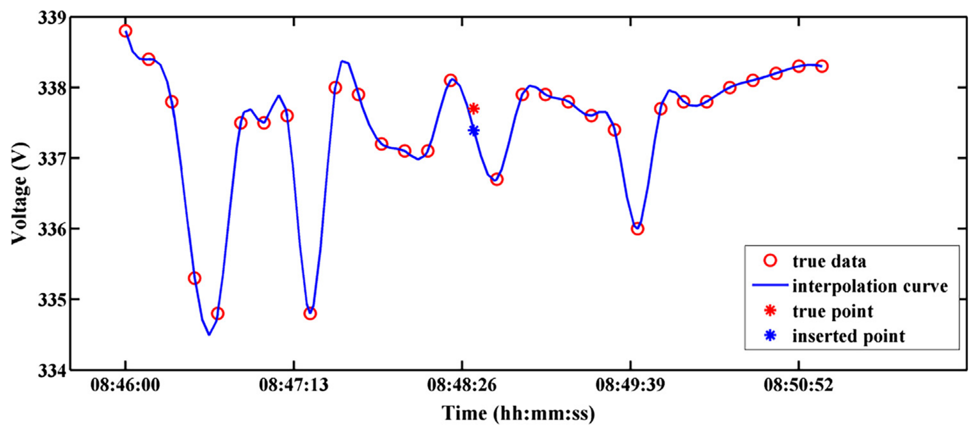

Fig. 1. Result of data processing.

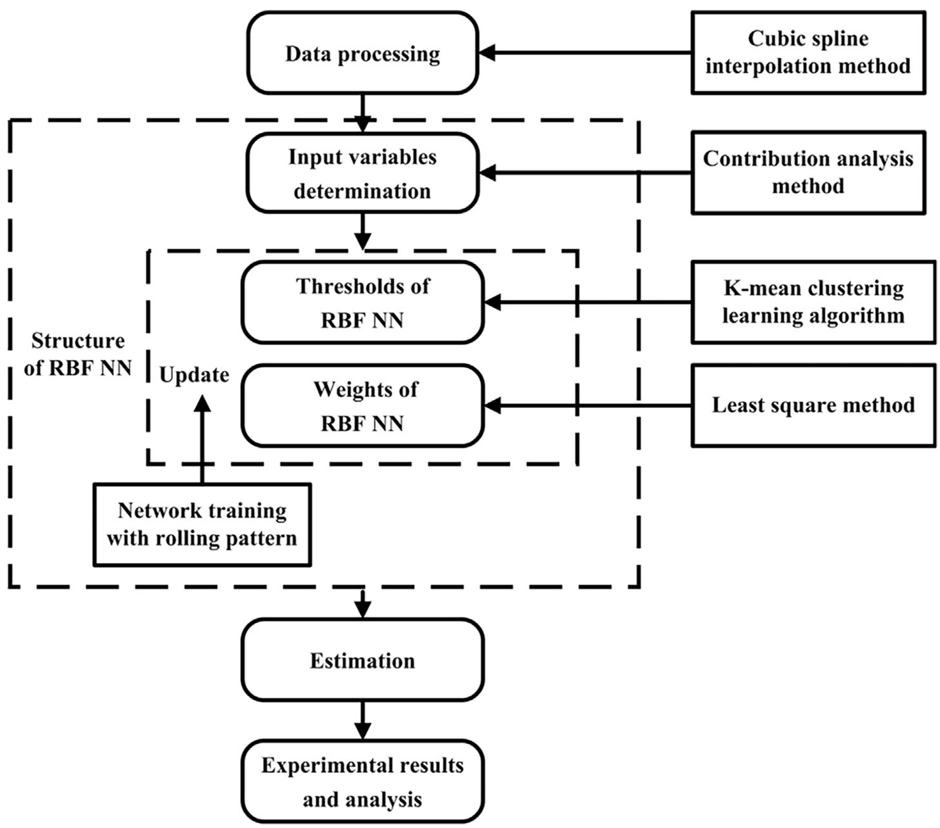

Fig. 2. Flow chart of residual range estimation process.

address EV problems, including energy management system development [9], online parameter identification [10], the prediction for the electrochemical characteristics of lithium-ion (Li-ion) cells [11], the estimation of the SOC [12,13], the state of health [14] and the residual capacity of batteries [15]. However, few studies have adopted the neural network methods to estimate the residual range of BEVs. In view of the several impacting factors for the range of BEVs, the residual range estimation is a complicated nonlinear problem with multiple variables. Therefore, special attention should be given to the introduction of the neural network methods for the residual range estimation problem.

In this study, based on the experimental data which are acquired from BEVs operating in Beijing, the radial basis function neural network (RBF NN) is applied to estimate the residual range of BEV. To simplify the RBF NN structure and enhance the performance of estimation, some important input variables of RBF NN are based on the contribution analysis method. To advance the real-time performance, an online training algorithm is applied in RBF NN trained by using historical data newly collected at a fixed time in current discharge process is discussed.

The rest of this paper is organised as follows. Section 2 discusses the background of the data. Section 3 illustrates the theory and method of estimation based on RBF NN. Section 4 presents the experimental results and analysis. Finally, Section 5 provides the conclusions of the study.

2. Data collection and processing

The data collection equipment in each BEV can online collect the battery, vehicular working status and GPS data via the internal CAN bus. The data are packed as a group, which is the combination of battery status, vehicle working status and GPS at the same second, and locally saved in the built-in flash memory every 10 s. The amount of