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Intelligent decision support platform of new energy vehicles

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Abstract: New energy vehicles (NEVs) are gaining wider acceptance as the transportation sector is developing more environmentally friendly and sustainable technology. To solve problems of complex application scenarios and multi-sources heterogenous data for new energy vehicles and weak platform scalability, the framework of an intelligent decision support platform is proposed in this paper. The principle of software and hardware system is introduced. Hadoop is adopted as the software system architecture of the platform. Master-standby redundancy and dual-line redundancy ensure the reliability of the hardware system. In addition, the applications on the intelligent decision support platform in usage patterns recognition, energy consumption, battery state of health and battery safety analysis are also described.

Keywords: new energy vehicle (NEV), intelligent decision support platform, software system, data platform application.

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1. Introduction

To promote economic transformation, optimize energy structure, and improve air quality, new energy vehicles (NEVs), including hybrid electric vehicles (HEVs), pure electric vehicles (PEVs), and fuel cell vehicles (FCVs), have become important initiatives and have entered a stage of rapid development [1]. China has become the world's largest national market for NEVs. In 2021, total NEV sales in China were 3.5 million, an increase of 145.6% compared to 2020, and 53% of all NEVs sold worldwide. However, safety issues are hindering the widespread use of NEVs in the global market. In 2018, more than 40 spontaneous combustion incidents of NEVs occurred in China. At the same time, the number of NEVs recalled has exceeded 130 000. Therefore, it is important to study a series of key technologies such as state of health (SOH), fault diagnosis, risk assessment, and precise control during the operation of NEVs, to effectively strengthen the safety supervision of NEVs.

In recent years, big data analytics has been gaining attention and shown good application prospects in the field of NEVs [2]. Along with the improvement of the onboard information system of NEVs and computer technology, a large amount of data are accumulated during charging and driving processes, such as structured data, and unstructured data [3]. Meanwhile, machine learning is playing an important role in NEVs' safety and intelligently decision systems [4]. Artificial intelligence (AI) has been applied to the field of NEVs, such as fault diagnosis [5], SOH [6], state of charge (SOC) [7], and prediction of battery cycle life [8].

According to the statistics of the China Academy of Information and Communications Technology (CAICT), as of May 2019, only 10 out of 36 major cities in China built city-level big data platforms, accounting for less than 30% in total [9]. Most of the big data platforms in the field of transportation are built without considering the application scenarios and reasonable data architecture of the transportation industry in a targeted manner. It brings problems such as difficult data aggregation, difficult analysis of the current situation and difficult decision support when analyzing data.

In order to solve the above problems, this paper designs a data architecture for real-time business support and offline data analysis in response to the data requirements in different scenarios. The intelligent decision support platform of NEVs is built.

The content of this paper is structured as follows: In Section 2, the decision support platform framework design is proposed. Section 3 discusses software and hardware framework. The conclusions are drawn from this research in Section 4.

2. Software and hardware system selection principles

2.1 Software system selection principle

The centralized deployment and unified management are

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adopted to ensure the consistency of data requirements and unified monitoring services.

To solve the problems of a large number, wide distribution, and difficult unified management of client-oriented, the decision support platform adopts the browser/server (B/S) architecture. And the B/S software architecture has the advantages of simple maintenance and upgrades because the main maintenance is on the server, greatly improving the maintenance efficiency [10]. With the development of geo-information technology in the field of the browser and the application of the rich Internet application (RIA), the adopted B/S architecture can meet the functional needs of users and bring convenience in performance and deployment.

As the number of NEVs connected to the decision support platform and the performance requirements of the platform increase, it is necessary to fully consider the scalability when building the platform. Therefore, the software with a good extensibility should be adopted.

2.2 Hardware system selection principle

The hardware application system is the core facility for the intelligent decision support platform, mainly including high-performance servers, high-capacity storage devices and network security devices. Among them, high-performance servers are used to provide fast and reliable computing, and high-capacity storage devices are used to store data. The performance of the hardware system will directly affect the accuracy and reliability of the whole platform.

Due to the complexity and specificity of the hardware application system, six principles need to be adopted when designing a hardware platform: unified planning, high availability, high scalability, high security, high maintainability, and suitable cost-performance.

(i) Unified planning: According to the scale of the application system during the planning period, the modules, users and processes of this application system are analyzed to determine the architecture and configuration of its hardware system.

(ii) High availability: The hardware platform needs to have a single point of failure, fault warning, and fault emergency handling capability. In case of failure of a limited number of servers, disks, storage devices, or switches, the system works properly without affecting business processing.

(iii) High scalability: Flexible expansion based on the original architecture is to deal with the insufficient processing power of the hardware platform. The scalability of the hardware system is divided into two main categories: vertical expansion and horizontal expansion. Vertical expansion means that the adapter can quickly support the new electronic components remote test system such as CPU, memory, channels, and boards of hardware devices [11]. Horizontal expansion can be achieved by replicating applications and increasing the number of application copies [12].

(iv) High security: The hardware system needs to have excellent information security and a flexible security strategy, such as partitioning of servers for different purposes to achieve different degrees of isolation.

(v) High maintainability: The effort for the maintenance is reduced. The downtime, especially those brought by repairing fault, upgrading or changing the system, is minimized. Thus, it provides user-friendly and comprehensive supervising tools.

(vi) Suitable cost-performance: On the premise of meeting demand, good cost performance is the key rather than blindly pursuing advanced technology. As long as the main problems can be solved, an appropriate cost performance strategy is a vital tool for the system.

3. Platform framework design

3.1 Software framework

The platform architecture is based on Hadoop, which consists of authentication and authorization, the data processing system, the big data basic system, the data analysis system, the application service system, and the big data visualization system, as shown in Fig. 1.

(i) Authentication and authorization

To enforce security policies and protect resources, the platform needs to authenticate and authorize users. Authentication is a prerequisite for authorization [13]. It is a process of getting and validating a user's identity. After that, the system can authorize the user's access to the desired resource. Authorization determines whether an authenticated user is permitted access to a resource and is based on the security policy. A policy is the definition of what is or is not permissible in the organization. A protection mechanism enforces security policies [14].

(ii) Data processing system

It belongs to the collection layer of the platform data. And it is responsible for receiving data transmitted by the provincial platform, enterprise platform, and sampling vehicles based on GB/T 32960-2016.

(iii) Big data basic system

It is divided into seven parts: high-speed queue message module, real-time data calculation module, real-time cache module, data bus interface modules, distributed file repository storage module, distributed indexing database module, and distributed relational database module.

(iv) Data analysis system

A large number of modules such as real time computing, offline computing, graph computing, and machine learning are utilized for data cleaning, charging behavior analysis, driving range analysis, driving behavior analysis, fault diagnosis, mileage verification, data auditing, daily reports, and other statistics and analysis.

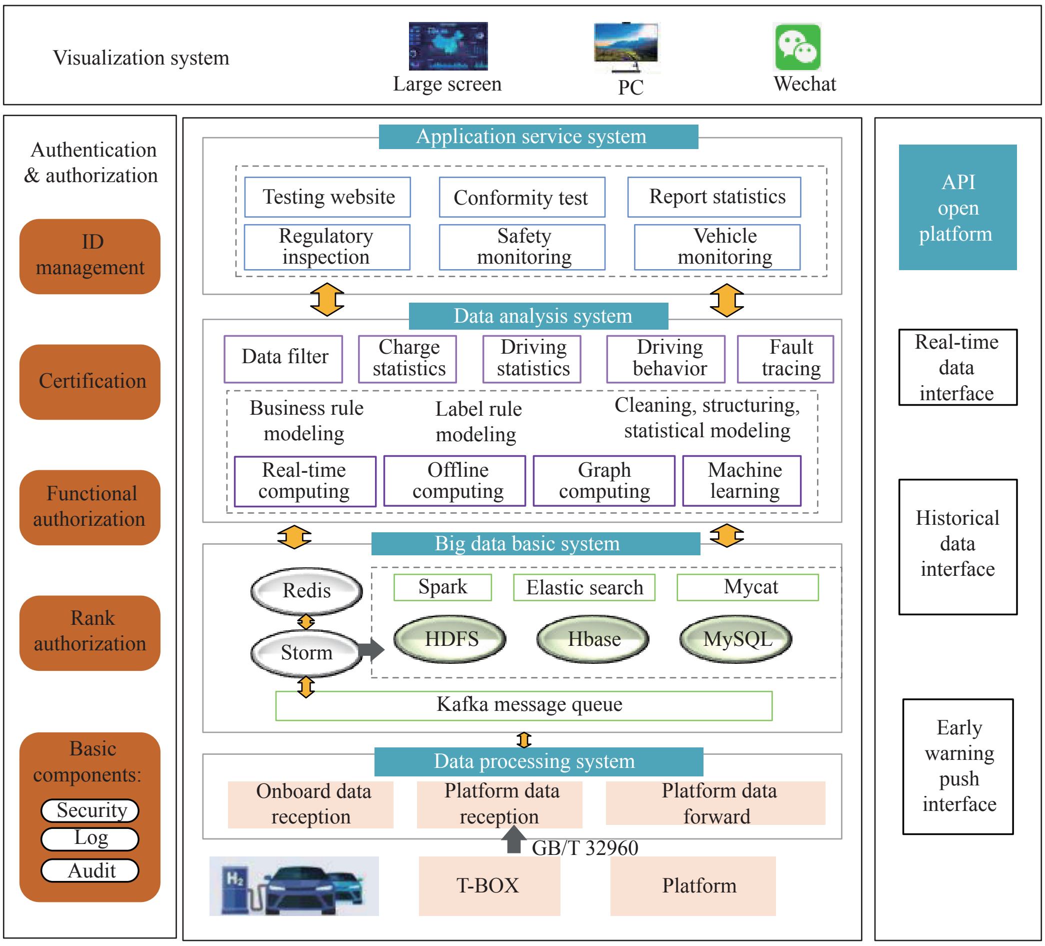

Fig. 1 Technical architecture

(v) Application service system

The application service system is divided into five parts: conformity test, vehicle monitoring, safety monitoring, report statistics, and application programming interface (API) open platform.

(vi) Big data visualization system

In this big data era, huge amounts of data are continuously acquired for a variety of purposes [15]. It includes large screen monitoring, mobile APP and WeChat service.

3.2 Hardware framework

The architecture scheme of hardware is shown in Fig. 2. The main-standby method is used to achieve equipment redundancy, and dual lines are utilized to achieve link redundancy. The network equipment redundancy method uses master-standby to eliminate a single point of failure and guarantee availability. The link redundancy method adopts link aggregation.

The network area mainly contains three parts: internet zone, demilitarized zone (DMZ), and intranet area.

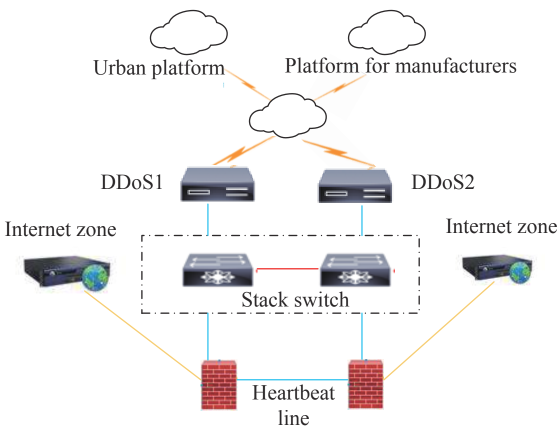

Fig. 2 Internet zone

(i) Internet zone

As shown in Fig. 2, the internet zone is a lower-level security area and an untrusted area in the interconnected network. When the external zone wants to access the hosts and services of the internal zone, restricted access can be achieved through the firewall.

Two distributed denial-of-service (DDoS) devices are redundantly configured to protect the platform from DDoS attacks on the external network. To ensure high reliability of internet access and network redundancy, two internet access switches with 20 G interconnection are selected to connect DDoS devices and firewalls.

The two internet multi-functional firewalls with the master redundancy mode provide security for mutual access between the internet zone, the DMZ zone, and the intranet zone. These firewalls take various functions such as traditional firewall, virtual private network (VPN), intrusion prevention, anti-virus, data leakage prevention, bandwidth management, anti-DDoS, uniform resource locator (URL) filtering, anti-spam, and so on. They can provide full VPN for internet protocol security (IPSec), secure sockets layer (SSL), layer 2 tunneling protocol (L2TP), multiprotocol label switching (MPLS), generic routing encapsulation (GRE) and others. Besides, over 6300 applications can be identified, for example, WeChat. In the same physical device, different users can be managed separately.

(ii) DMZ

A buffer zone between the non-secure system and the secure system called DMZ is set up to solve the problem that the external network cannot access the internal network servers after the firewall is installed as shown in Fig. 3. The DMZ is located in a small network area between the internal network and the external network, where some public server facilities, such as corporate web servers, web servers, front-end processor, load balancer, can be installed. The DMZ zone can effectively protect the internal network and provide an additional barrier to attackers than a typical firewall solution. External users are usually allowed to access the public information of the enterprise, but they are not allowed to access the internal network. The two web application firewalls (WAFs) can provide security protection including security protection against tampering, stealing database information and other illegal operations. Two switches with dual-active configuration are used to realize a reliable and fast interaction network in DMZ. Two load balancers with dual-active devices are able to achieve load balancing of internal applications.

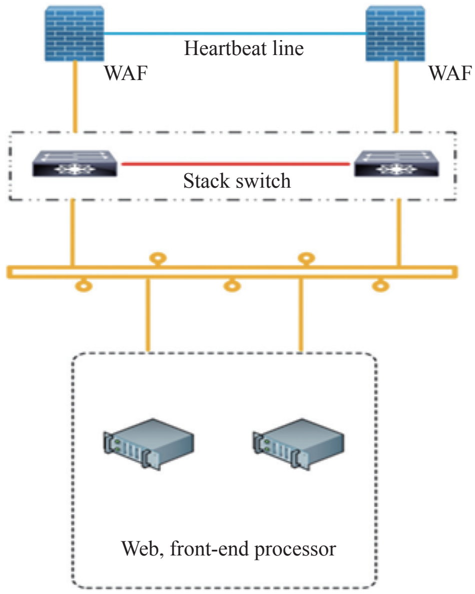

Fig. 3 DMZ architecture

(iii) Intranet area

The intranet area needs the highest level of security, where the core data are located, such as big data storage and analysis servers, virtual machine (VM) servers and database servers, as shown in Fig. 4. Before flowing via the gateway firewall and into the server farm, data entering the intranet from the DMZ area first pass through the intrusion prevention system (IPS), then the cluster switch system (CSS).

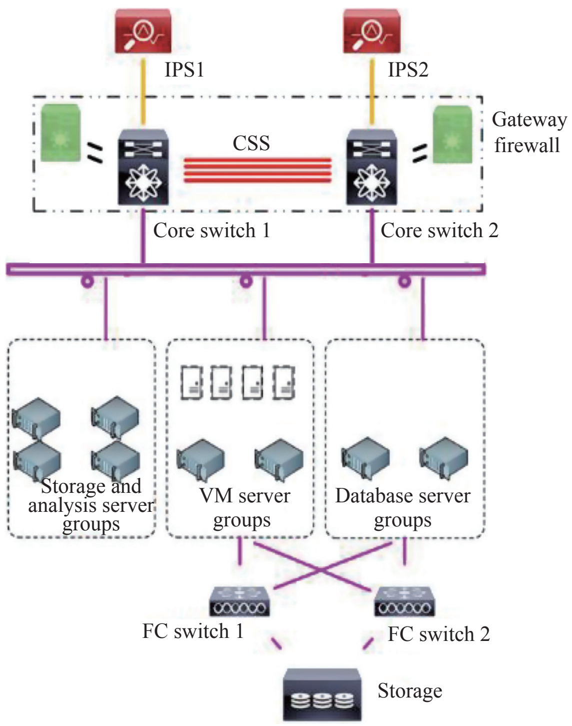

Fig. 4 Intranet area architecture

As the core of intranet servers communicating with each other, two intranet core switches are responsible for all core data interactions and provide large traffic interaction between intranet servers. The stacking bandwidth of 3.2 Tbps is used to avoid network traffic. The service port clustering technology is adopted to support long-distance stacking with up to 80 km.

Ten access switches are stacked in groups of two through 40 G network, with 80 G interaction bandwidth between the two switches. Each group of switches is connected to the core switch through four 40 G fiber optic cables, providing 160 G network bandwidth for uplink, and servers are connected to two access switches with 10 G fiber respectively.

Database servers, VM servers and storage devices are connected to two fiber channel (FC) switches via 8 G FC interfaces for server-to-storage multipathing. The centralized storage has two controllers, each with two 8 G fibers connected to two FC switches, guaranteeing port and controller redundancy.

According to the network architecture design plan and the demand for equipment in each region, a summary of the hardware required for equipment in each region is carried out, as shown in Table 1.

Table 1 Equipment and usage description of network area

Architecture	Equipment	Usage
Internet zone	DDoS	Anti-DDoS attack
	Internet access switch	External network access
	VPN	SSL VPN
	Internet firewall	Security strategy
DMZ	WAF	Seven layers of application protection
	DMZ switch	Three-layer interconnection
	Load balancer	Seven-tier load balancing
	DMZ server	External service web and front-end services
Intranet area	Intrusion detection equipment	Intrusion detection
	Core switch	Exchange
	Access switch	Access server
	Load balancer	Four-tier load balancing
	Leak sweep & certification audit	Vulnerability scanning, authentication auditing
	Intranet server	Service to DMZ’s servers
	Virtualized servers	Virtualization of applications
	FC fiber optic switch	Storage network
	Storage	Database and virtualized storage

4. Application of intelligent decision support platform

A large amount of NEV data is available in the intelligent decision support platform, including battery system status, vehicle position and speed. The power battery data of the whole life cycle includes cell voltage, total voltage, temperature and SOC [16]. The intelligent decision support platform has been applied to the analysis of power battery data, vehicle operation data and charging data [3].

As shown in Fig. 5, Cui et al. [17] studied NEVs’ usage patterns to provide decision-making for the charging infrastructures, battery charging schedule, and grid load forecast. Zhang et al. [18] analyzed the influencing factors of energy consumption and proposed a novel machine learning-based energy consumption prediction framework to support the NEVs driver services and city transportation optimization, such as remaining range prediction, intelligent navigation and charging infrastructures operation.

Many related works have been carried out to investigate the SOH and safety of NEVs in the intelligent decision support platform. She et al. [19] proposed the battery aging assessment model using incremental capacity analysis and radial basis function neural network. Wang et al. [20] suggested the Mahalanobis distance in combination with density-based spatial clustering of applications with noise (MD-DBSCAN) to evaluate battery consistency. As shown in Fig. 6, Wang et al. [21] employed Shannon entropy and Z-score to identify cells with abnormal voltage fault. Gan et al. [22] proposed a machine learning based two-layer overdischarge fault diagnosis strategy for electric vehicles. Sun et al. [23] built a scheme of three-layer fault detection method for lithium-ion batteries based on statistical analysis. All the above methods have been used in the intelligent decision support platform.

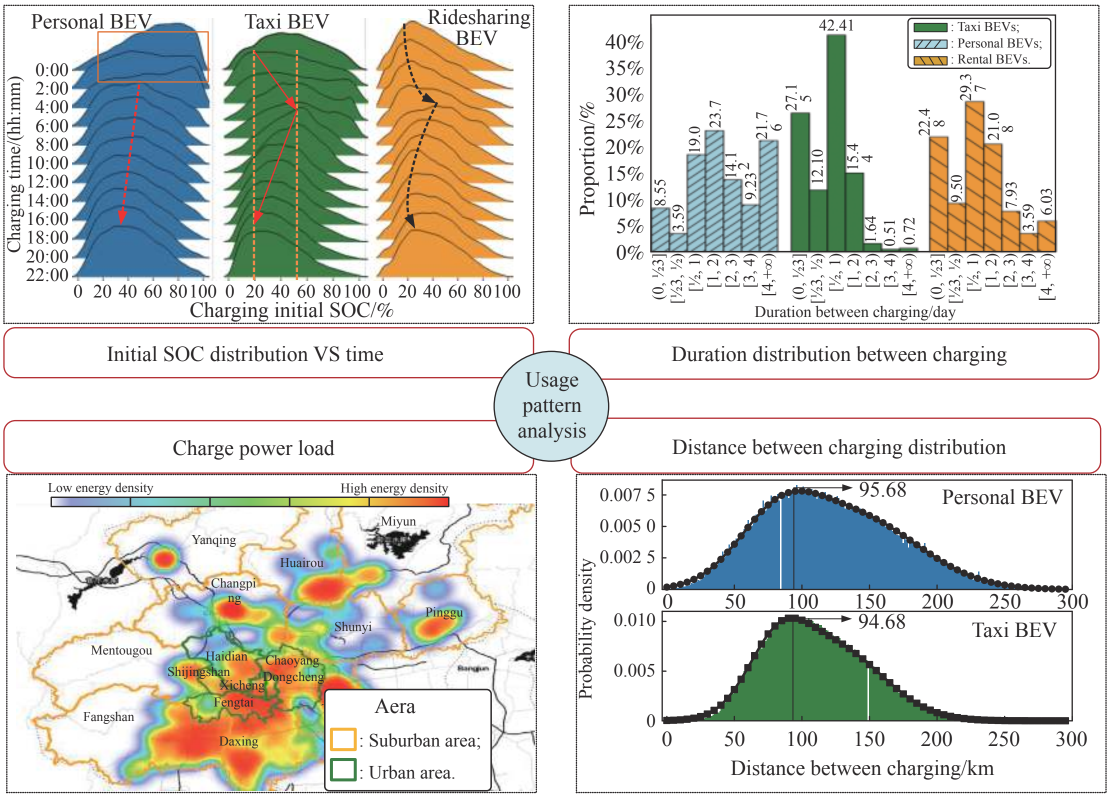

Fig. 5 Usage pattern analysis

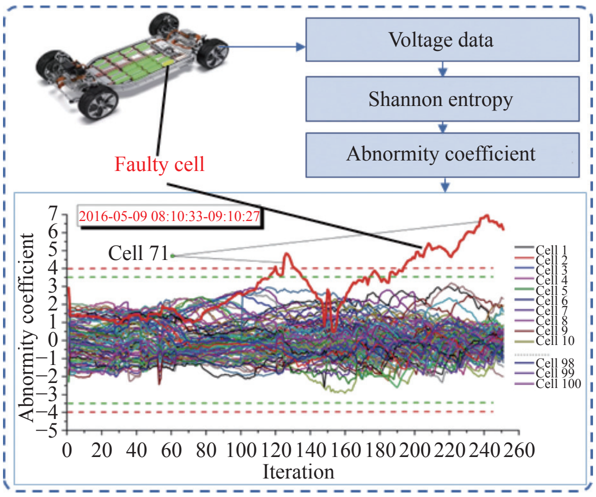

Fig. 6 Algorithm for battery safety of NEVs [21]

5. Conclusions

In this paper, an intelligent decision support platform for NEVs has been constructed. For software selection principles, centralized deployment and unified management have been adopted. For hardware selection principles, six principles including unified planning, high availability, high scalability, high security, high maintainability, and suitable cost-performance have been fully considered. The software architecture of the platform has been based on Hadoop. The network area mainly has contained three parts: internet zone, DMZ, and intranet area. We have applied multiple machine learning methods to this platform to discover driving usage patterns, analyze NEVs' energy consumption and ensure battery safety. This platform has been used for vehicle management in the public sector and has served for the safety and operation management of NEVs for the Beijing Winter Olympics 2022.

References

[1] ZHU X Q, WANG Z P, WANG C, et al. Overcharge investigation of large format lithium-ion pouch cells with Li($Ni_{0.6}Co_{0.2}Mn_{0.2}$)O_2 cathode for electric vehicles: thermal runaway features and safety management method. Energy, 2019, 169: 868–880.

[2] BIBRI S E. Big data science and analytics for smart sustainable urbanism: unprecedented paradigmatic shifts and practical advancements. Berlin: Springer, 2019.

[3] SHE C Q, ZHANG Z S, LIU P, et al. Overview of the application of big data analysis technology in new energy vehicle industry: based on operating big data of new energy vehicle. Journal of Mechanical Engineering, 2019, 55(20): 3–16.

[4] TURNER C J, EMMANOUILIDIS C, TOMIYAMA T, et al. Intelligent decision support for maintenance: an overview and future trends. International Journal of Computer Integrated Manufacturing, 2019, 32(10): 936–959.

[5] LI D, ZHANG Z S, LIU P, et al. Battery fault diagnosis for electric vehicles based on voltage abnormality by combining the long short-term memory neural network and the equivalent circuit model. IEEE Trans. on Power Electronics, 2021, 36(2): 1303–1315.

[6] SHE C Q, ZHANG L, WANG Z P, et al. Battery state of health estimation based on incremental capacity analysis method: synthesizing from cell-level test to real-world application. IEEE Journal of Emerging and Selected Topics in Power Electronics, 2022. DOI: 10.1109/JESTPE.2021.3112754.
[7] ZHENG Y J, GAO W K, OUYANG M G, et al. State-of-charge inconsistency estimation of lithium-ion battery pack using mean-difference model and extended Kalman filter. Journal of Power Sources, 2018, 383: 50–58.
[8] SEVERSON K A, ATTIA P M, JIN N, et al. Data-driven prediction of battery cycle life before capacity degradation. Nature Energy, 2019, 4(5): 383–391.
[9] China Academy of Information and Communications Technology. Urban big data platform white paper. http://www.caict.ac.cn/kxyj/qwfb/bps/201906/P020190604489340368704.pdf.
[10] MAO L D, MIAO J. Application of browser/server architecture in college English online learning system design. International Journal of Emerging Technologies in Learning, 2018, 13(3): 129–140.
[11] LIU X R. Hardware design of electronic components remote test adapter based on information processing. Proc. of the International Conference on Big Data Analytics for Cyber-Physical System in Smart City, 2022, 102: 449–456.
[12] XIA Y Q. Resource scheduling for piano teaching system of internet of things based on mobile edge computing. Computer Communications, 2020, 158: 73–84.
[13] KIM H, LEE E A. Authentication and authorization for the internet of things. IT Professional, 2017, 19(5): 27–33.
[14] KRZYZANOWSKI P. Computer security. https://people.cs.rutgers.edu/~pxk/419/notes/access.html.
[15] AGRAWAL R, KADADI A, DAI X F, et al. Challenges and opportunities with big data visualization. Proc. of the 7th International Conference on Management of Computational and Collective Intelligence in Digital EcoSystems, 2015: 169–173.
[16] SUN Z Y, WANG Z P, CHEN Y, et al. Modified relative entropy based lithium-ion battery pack online short circuit detection for electric vehicle. IEEE Trans. on Transportation Electrification, 2022, 8(2): 1710–1723.
[17] CUI D S, WANG Z P, LIU P, et al. Battery electric vehicle usage pattern analysis driven by massive real-world data. Energy, 2022, 250: 123837.
[18] ZHANG J, WANG Z P, LIU P, et al. Energy consumption analysis and prediction of electric vehicles based on real-world driving data. Applied Energy, 2020, 275: 115408.
[19] SHE C Q, WANG Z P, SUN F C, et al. Battery aging assessment for real-world electric buses based on incremental capacity analysis and radial basis function neural network. IEEE Trans. on Industrial Informatics, 2020, 16(5): 3345–3354.
[20] WANG Q S, WANG Z P, ZHANG L, et al. A novel consistency evaluation method for series-connected battery systems based on real-world operation data. IEEE Trans. on Transportation Electrification, 2020, 7(2): 437–451.
[21] WANG Z P, HONG J C, LIU P, et al. Voltage fault diagnosis and prognosis of battery systems based on entropy and Z-score for electric vehicles. Applied Energy, 2017, 196: 289–302.
[22] GAN N F, SUN Z Y, ZHANG Z S, et al. Data-driven fault diagnosis of lithium-ion battery over discharge in electric vehicles. IEEE Trans. on Power Electronics, 2022, 37(4): 4575–4588.
[23] SUN Z Y, HAN Y, WANG Z P, et al. Detection of voltage fault in the battery system of electric vehicles using statistical analysis. Applied Energy, 2022, 307: 118172.

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