Research on the Challenges and Optimization Path of Fault Diagnosis Technology for Intelligent New Energy Vehicles

Xu Zhang

Shandong Polytechnic College, Jining, Shandong, China

Abstract

With the continuous increase in the number of new-energy vehicle owners and the rapid development of intelligent connected functions, vehicle failure modes are gradually changing from traditional mechanical wear to complex anomalies caused by the combined effects of batteries, motors, electronic control systems, software and communication modules, etc. Fault diagnosis ability is now required to ensure the safety of the car and the user experience; otherwise, after-sales service will be affected. Currently, intelligent fault diagnosis for new-energy vehicles still faces several problems in its technological application, such as complex fault mechanisms, fragmented data resources, insufficient adaptability of diagnostic models, imperfect service collaboration mechanisms, unclear data security responsibility boundaries, and a shortage of multi-skilled maintenance personnel. Addressing these challenges, this article analyzes the operational logic and application value of intelligent new energy vehicle fault diagnosis, proposing a diagnostic optimization system based on data governance, supported by collaboration between the vehicle, cloud, and service ends, and guaranteed by standards, privacy protection, and talent cultivation. This system should cover status perception, anomaly identification, risk warning, maintenance decision-making, and feedback updates. The study argues that intelligent fault diagnosis should not be limited to single-point detection and fault code identification but should be integrated into the entire lifecycle management process of new energy vehicles, thereby improving vehicle safety management and the resilience of the after-sales service system.

Keywords

Intelligent new energy vehicles, fault diagnosis, data governance, intelligent operation and maintenance, optimization path.

1. Introduction

New energy vehicles are the carriers of the green and intelligent transformation of the automotive industry. With the continuous integration of power batteries, drive motors, vehicle controllers, vehicle operating systems and vehicle networking platforms, the structure of vehicles has changed from traditional mechanical devices to complex electromechanical and software integrated systems. Vehicle operation safety is no longer affected by the quality of individual components. It is closely related to energy management, thermal management, communication stability, software version adaptation, user usage scenarios, etc. [1]. In this case, fault diagnosis has gradually developed from an auxiliary means in the maintenance process to the foundation for ensuring vehicle safety supervision, improving after-sales service quality and improving product quality.

Traditional vehicle fault diagnosis relies on human experience, fault light prompts and offline testing equipment. The main diagnostic targets are the engine, transmission system and mechanical parts. Faults in intelligent new energy vehicles are highly concealed and coupled. Range reduction may be caused by battery aging, low temperature environment, thermal

management efficiency, driving habits, software control strategies, etc.; charging abnormalities also involve battery management system, charging facilities, communication protocols, safety protection logic and other aspects. If a single-point detection method is still adopted, it will cause a delay in fault location, increase maintenance costs and reduce user trust in the system [2-3]. Therefore, intelligent new energy vehicle fault diagnosis technology must ensure systematic integration between data acquisition, status identification, risk prediction, and service response. This paper focuses on the practical challenges and optimization approaches of intelligent new energy vehicle fault diagnosis technology, providing a reference for improving the aftermarket service system for new energy vehicles, managing the entire vehicle lifecycle, and enhancing intelligent operation and maintenance capabilities.

2. Technical Connotation and Operational Logic of Fault Diagnosis in Intelligent New Energy Vehicles

Intelligent new energy vehicle fault diagnosis is a complete set of technical systems that use on-board sensors, vehicle controllers, remote service platforms, maintenance terminals, and fault knowledge bases to continuously monitor the vehicle's operating status, identify anomalies, analyze causes, and support maintenance decisions. Its diagnostic objects are not only power batteries, motor and electronic control, thermal management systems, and charging systems, but also new modules such as intelligent cockpits, assisted driving, on-board communication, and software upgrades [4].

From an operational logic perspective, intelligent diagnostics requires a wealth of vehicle operating data, including voltage, current, temperature, SOC, SOH, energy consumption, mileage, charging records, fault codes, and software logs. This data is then cleaned and filtered to remove abnormal data, communication losses, and noise. Next, fault rules, past cases, and model inferences are used to determine the location of the anomaly. Finally, based on the level of fault risk, repair suggestions are provided and communicated to the knowledge base. This process has a closed-loop characteristic, which promotes continuous improvement of diagnostic capabilities through ongoing use (Figure 1).

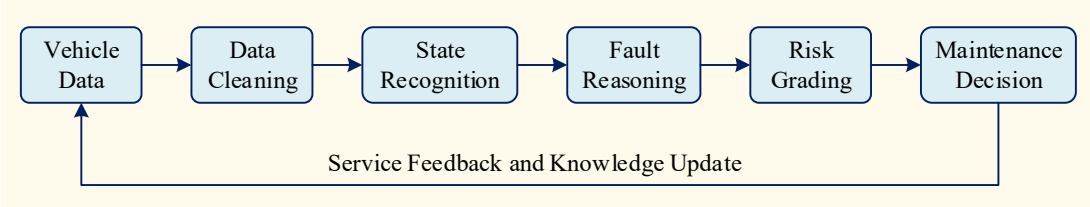


Figure 1. Process of Intelligent NEV Fault Diagnosis

Compared with traditional maintenance diagnosis, intelligent diagnosis has three advantages. First, it can detect abnormalities in advance, so that risks can be alerted and discovered before damage occurs. Second, it can improve the accuracy of maintenance decisions and reduce repeated testing and misjudgments caused by personal experience and subjective judgment [5]. Third, it can promote the exchange of data among car manufacturers, car sales companies and car service stations, providing more sufficient basis for improving vehicle quality and after-sales service.

More importantly, intelligent fault diagnosis is changing the way after-sales services for new energy vehicles are organized. In the past, repair services mostly started from users actively reporting problems, and it was difficult for companies to know about the hidden risks of vehicles; while intelligent diagnosis links vehicle status monitoring, risk warnings, service

appointments, and quality traceability, turning after-sales service from a passive response to proactive management.

3. Major Challenges in Fault Diagnosis Technology for Intelligent New Energy Vehicles

3.1. Complexity and Concealment of Fault Mechanisms

The failure of intelligent new energy vehicles is not caused by the failure of a single component, but by the combined result of the coupled operation of multiple systems. Abnormal power battery temperature is related to factors such as ambient temperature, thermal management methods, fast charging rate and cell consistency, while the fluctuation of motor output is dominated by battery supply capacity, controller response speed, sensor status and vehicle control algorithm. The fault phenomenon and the fault cause are not directly related, which increases the complexity of fault diagnosis and interpretation [6].

Many other faults are also gradual and insidious. Battery capacity degradation, reduced insulation performance, increased communication latency and abnormal software status are not likely to cause the vehicle to stop working immediately, but they can gradually lead to a dangerous situation. If these faults are not continuously monitored and trended, a safety accident or high-cost repair will occur later.

A single-point failure cannot be ruled out. If the fault results from user behaviour, vehicle design, component quality or software control logic, it will be difficult to determine the liable party without sufficient data to support this conclusion at the repair end. This will reduce the efficiency of repairs and cause user complaints and after-sales service disputes [7].

3.2. Data Resource Fragmentation and Insufficient Standardization

Data are the foundation of intelligent fault diagnosis, but the new-energy-vehicle industry chain still faces problems such as inconsistent data standards, poor interface openness, and a lack of accumulated fault cases. Different car companies have different standards for data items, collection frequency, fault codes and platform interfaces, and thus it is difficult to obtain an all-encompassing, consistent and easy-to-understand picture of the car's condition for repair shops. In some third-party repair scenarios, only a limited number of fault codes can be read, which cannot be combined with the vehicle's historical operating data for diagnosis.

Data fragmentation can also hinder the establishment of fault knowledge bases and model migration. If the same type of fault is represented differently in different brands, models, and platforms, diagnostic experience cannot be accumulated to form industry-wide common knowledge, and models will be difficult to promote and use across different models. This will not only slow down the diagnostic process but also hinder the standardization of aftermarket services for new energy vehicles (Figure 2).

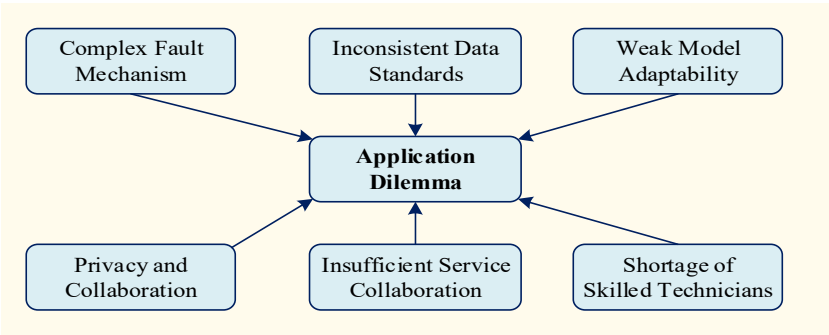


Figure 2. Key Problems of Intelligent Fault Diagnosis.

In the long run, inadequate data standardization and collaboration will lead to a decline in the industry's public service capabilities. Safety risks in new energy vehicles are cross-regional, cross-brand, and cross-use scenarios. Establishing a unified data representation and case retention system would make fault prediction, quality tracking, and repair services more organized.

3.3. The Diagnostic Model Lacks Scenario Adaptability.

Intelligent diagnostic models typically rely on historical data and typical rules to operate, but the actual vehicle operating environment is highly random. Low temperatures, high temperatures, traffic congestion, fast charging, high-speed driving, mountain roads, and vehicle aging can all cause fault manifestations to change. Some models can identify common anomalies under standard operating conditions, but they may still make mistakes or miss reports when encountering extreme operating conditions, multiple faults overlapping, or low-probability safety events.

In addition, the interpretability of diagnostic results needs to be improved. Maintenance personnel and users cannot simply stop at "whether there is a fault," but must also have a clear understanding of the source of the anomaly, the risk level, the priority of handling, and the basis for maintenance. If the system only outputs fault codes and probability results without root cause analysis or handling suggestions, it will fail to be an effective maintenance service.

3.4. The After-sales Service System is not Commensurate with Professional Capabilities.

Maintenance of intelligent new-energy vehicles is no longer confined to mechanical repairs; now, it also covers high-voltage safety, battery management, software diagnosis and communication protocol analysis, data analysis, etc. Some grassroots repair shops do not have special test instruments, remote diagnosis devices, or trained staff, so the application of intelligent diagnosis has not been effective.

Car manufacturers, platforms and repair shops have not coordinated the service process. When there is an abnormality in the vehicle, how quickly the diagnostic results of the platform can be communicated to a repair shop, whether the results from the repair shop can be returned to the platform, and whether users are informed of the repair status in an open and transparent manner all affect the value of intelligent diagnostic technology.

3.5. Data Security and Responsibility Boundary Pressures

Data for the fault diagnosis system need to be collected on vehicle operation, charging, maintenance and use. The data has both technical value and problems of user privacy and business security. If the scope of data collection is not specified, the authorisation system is vague, and responsibility for sharing cannot be determined, users will lose trust in the platform and there may be misuse of data and disputes over platform liability.

Therefore, the data security and responsibility attribution of the intelligent diagnostic system must also be addressed. Data usage should aim to find faults, issue risk warnings and provide maintenance services, and methods such as data anonymisation, tiered authorisation, security auditing and access control can be employed to reduce risks.

4. Optimization Path of Fault Diagnosis Technology for Intelligent New Energy Vehicles

4.1. Improve the Data Governance and Standard Interface System

To strengthen the foundation of data support for the intelligent fault diagnosis module, first collect and process data. In accordance with the relevant specifications of the electric vehicle

remote service and management system, the creation of data collection, storage, labelling and sharing guidelines should be carried out for power batteries, motor control, charging system, thermal management system, vehicle software, communication modules, etc. Standardise the coding of serious fault information, record details about the abnormality, risk level and maintenance actions, and thus reduce the chance of data inconsistency among different parties.

Data interfaces should be used to release some diagnostic data in an organised way within safe limits, and repair shops need to be able to obtain this information for diagnosis of vehicle problems. Build reusable case libraries and knowledge bases for common industry-wide faults to support the training of diagnostic models and the accumulation of repair experience.

4.2. Constructing a Closed-loop Diagnostic System from Vehicle to Cloud to Server

Intelligent fault diagnosis should transition from a reactive mode after a fault occurs to a closed-loop management system that observes the circumstances, issues risk alerts, arranges for maintenance, and offers feedback. Collect real-time operating data from the vehicle end, analyse and categorise it in the cloud, have the server-side develop maintenance plans, manage users and feedback, etc. The three links in this chain must be kept whole; otherwise, there will be a fault in the diagnosis.

Different response modes need to be used for different levels of faults. A minor problem can be addressed remotely through an alarm or software update, and otherwise will gradually be revealed. Schedule an inspection for the medium-risk anomaly. High-risk abnormalities should be accompanied by a safety warning and instructions to stop using or repairing immediately. Complete the repair, notify the platform of the actual reason for the problem and how it has been resolved, and update the knowledge base at the same time.

4.3. Improve Model Interpretability and Dynamic Update Capability

The improvements in the diagnostic model should be highly accurate, generalisable and explainable. A model should not be based on a single fault code; rather, many factors such as vehicle operating data, the environment, maintenance history and user characteristics need to be considered for multi-source fusion diagnosis. The system should be able to offer relatively complex fault diagnosis results, such as the cause ranking, risk level and corresponding solutions, and help maintenance staff plan repairs promptly (Figure 3).

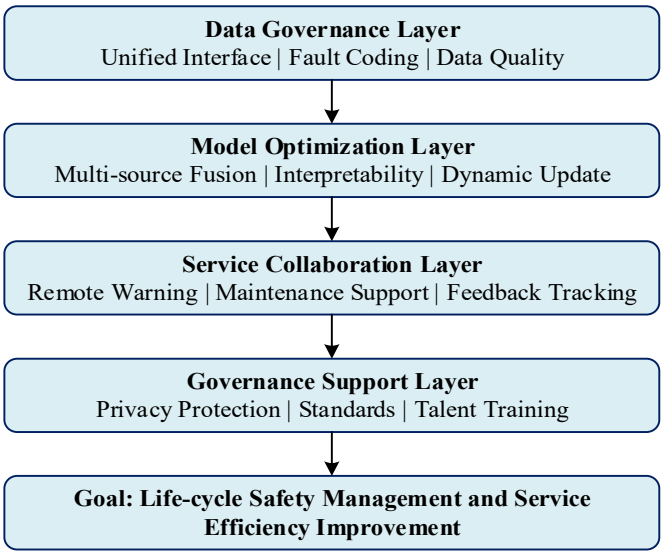


Figure 3. Optimization Framework for Intelligent NEV Diagnosis.

The condition of the vehicle changes with age, the number of charging cycles and operating environment; thus, diagnostic models should also support dynamic updates. Continuously integrate and update the new maintenance feedback, abnormal event data and newly added vehicle model information to improve the model's matching accuracy with real-life conditions, reduce errors caused by differences in vehicle models, regions or changes in the lifecycle stage, etc.

Add version management and performance evaluation for the model in the model manager. When revising the diagnostic rules, all the above factors should be considered; that is to say, the false alarm rate, the false negative rate, maintenance verification, user feedback, and so on, should all be taken into account, and only technical factors should not be emphasized at the expense of real-world application. Model optimisation should be connected with the actual maintenance closed-loop, and a verifiable and traceable improvement process should be created.

4.4. Improve Industry Collaboration and After-sales Service Mechanisms

To improve the efficiency of intelligent fault diagnosis, cooperation at all levels of the industry chain is needed. Car companies will provide relevant diagnosis data and technological innovation support; platform companies will strengthen data processing and result interpretation; repair shops should meet service standards and promptly inform users of the repair results; industry organisations and regulatory authorities need to lead the development of standards and enhance service specifications. Only in a multi-party collaboration can fault diagnosis be changed from a single-stage function to an all-encompassing service mode.

The model of after-sales service should change from the original "repair in-store after a fault" to "remote early warning, proactive service and all-round health management". The diagnostic platform will promptly identify any problems; at the same time, the repair company will have prepared necessary spare parts and workstations in advance, and the user will receive timely service notifications and appointment information to enhance the quality and level of service.

Generally speaking, fault codes should not be used instead of explanations for the service process in user inquiries. The repair shop should explain the fault symptoms, probable causes, risk level and repair methods of the test results in a simple way for the user. Open-book services reduce information asymmetry and enhance user trust in new-energy-vehicle repair services.

4.5. Improve the Data Security and Talent Support Mechanism

Data security should be based on the principle of least privilege, and the scope of vehicle data collection and use purpose should be limited as much as possible, along with retention time and sharing boundaries. Anonymise and authorise the collection of personal data on a user's journey, charging site, etc. A system will be built to record abnormal access, data leakage and other unauthorised uses of the platform.

Strengthen the cultivation of multi-skilled maintenance staff by enhancing talent development. Vocational schools, automakers and maintenance platforms can build training modules on the safety of power batteries, electronic control systems, intelligent connectivity, software diagnostics and data analysis to enhance the maintenance staff's knowledge and application of intelligent diagnostic tools. Only when both the personnel's ability and the technical system are strengthened at the same time will intelligent fault diagnosis truly improve vehicle safety and meet user demands.

Add a tiered training and competency certification system at the same time. Strengthen the high-voltage safety awareness, fault-reading and basic-level diagnosis skills of frontline maintenance staff; improve the data analysis and complex fault analysis capabilities, learn to operate the remote platform for technical supervisors, and enhance the user communication

skills and quality-traceability system of service management staff; implement risk control measures.

4.6. Improve the Risk Classification and Quality Traceability Mechanism

The creation of clear risk classification rules for intelligent fault diagnosis needs to be done, and fault hazards should be divided into alert, warning, restricted-use, and emergency-response categories. The different levels are for different service response speeds and handling methods, so no repair will be needed for low-risk anomalies, and high-risk faults will not cause delays. Dynamically adjust the risk level according to the age of the car, driving conditions and any previous malfunctions.

Build a Quality Traceability System. After the repairs are finished, the reason for the malfunction, how it was handled, which parts were replaced, and the results of re-inspection by the user need to be recorded and reported to the vehicle manufacturer and the platform. Continuously accumulate real repair data to identify common quality problems in the products, optimize product design and service processes, and advance fault diagnosis from a case-by-case approach to industry-wide quality improvement.

5. Conclusion

Intelligent fault diagnosis technology for new-energy vehicles can help to improve driving safety, optimise after-sales service, and strengthen the quality management system of the whole-vehicle enterprise. As the intelligence level of new-energy vehicles continues to rise, so too has the range of fault diagnosis expanded; now, many non-traditional areas such as batteries, motors, electronic control units, software, communication systems, and service platforms are included. Additionally, diagnostic methods have moved away from experience-based judgment to data-driven and platform-collaborative approaches gradually.

At present, intelligent fault diagnosis faces many problems, such as complex fault modes, fragmented data resources, non-applicable models, weak service cooperation, a heavy data security burden, and a shortage of professional talents. To systematically address these problems in the future, all levels of the system will be improved in terms of data governance, standardised interfaces, diagnostic closed-loop systems, model optimisation, industry cooperation, security protection and talent training. Intelligent fault diagnosis will gradually change from a maintenance-aid tool to the foundation of whole-life management for new-energy vehicles, play an increasingly important role in vehicle safety supervision and user service improvement, and promote high-quality industrial development.

References

[1] General Office of the State Council of the People's Republic of China. (2020). *Development Plan for the New Energy Vehicle Industry (2021–2035)*. http://www.mee.gov.cn/zcwj/gwywj/202011/t20201103_806156.shtml

[2] State Administration for Market Regulation, & Standardization Administration of China. (2016). *Technical specifications of remote service and management system for electric vehicles-Part 1: General principle* (GB/T 32960.1-2016). http://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D81157D3A7E05397BE0A0AB82A

[3] State Administration for Market Regulation, & Standardization Administration of China. (2016). *Technical specifications of remote service and management system for electric vehicles-Part 3: Communication protocol and data format* (GB/T 32960.3-2016). http://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D810F7D3A7E05397BE0A0AB82A

[4] State Administration for Market Regulation, & Standardization Administration of China. (2020). *Electric vehicles safety requirements* (GB 18384-2020). http://std.samr.gov.cn/gb/search/gbDetailed?id=A5835FE0ED57032FE05397BE0A0A540B

[5] State Administration for Market Regulation, & Standardization Administration of China. (2024). *Technical requirement for maintenance and repair of new energy vehicle* (GB/T 44510-2024). http://std.samr.gov.cn/gb/search/gbDetailedCNF?id=234D7936AA3BE194E06397BE0A0AA0A9

[6] International Organization for Standardization. (2018). *Road vehicles-Functional safety* (ISO 26262:2018). https://www.iso.org/publication/PUB200262.html

[7] International Organization for Standardization, & SAE International. (2021). *Road vehicles-Cybersecurity engineering* (ISO/SAE 21434:2021). https://www.iso.org/standard/70918.html