Research on the Key Technology of Safety Monitoring for China Railway High-speed Based on Information Fusion

Jie Xu, Yan Wang, Lei Liu
Hebei Vocational College of Rail Transportation, Shijiazhuang, 050000, China

Abstract

Railway is the important lifeline of our national economy, whose transportation safety is a key factor affecting the sustainable development of railway industry. Since the proposal of the Eleventh Five-Year Plan, the relevant railway departments have been constantly strengthening the modernization of their security detection system and traffic safety monitoring system, innovating the management mode and enhancing the prevention of security risks. The measures greatly improve the overall capacity of railway traffic safety and contribute to the current stable and controllable situation. With the rapid development of high-speed railway and the application of a large number of advanced technologies in recent years, new requirements have been proposed for the security of the high-speed EMU. This paper first summarizes the research background and clarifies the research objectives according to the literature review, based on which the modeling process of high-speed EMU safety monitoring information fusion is analyzed according to the overall modeling thinking and the specific modeling methods. And then the main algorithms of the security monitoring information fusion model are elaborated for the in-depth research on the key technology of the high-speed EMU safety monitoring system, i.e. the infrared hotbox technology. Under this technical support, the prediction system of high-speed EMU security monitoring system is constructed for further guarantee of the traffic safety of high-speed EMU, promoting the sustainable development of railway industry.

Keywords: Information Fusion, High-Speed Emu, Safety Monitoring System, Key Technology

1. THE RESEARCH BACKGROUND

1.1 Literature review

The construction and development of the high-speed EMU safety monitoring system is an important foundation to ensure the realization of harmonious railways. The relevant practices in the development of high-speed trains show that safety is the main artery and the tenet of railway industry; without guarantee of traffic safety, there would be no efficiency and economic benefits (Sun, 2010). Therefore, the railway undertakings of China have paid great attention to the EMU safety in recent years and regard it as the fundamental element to promote their own development by adhering to the “three consensuses” and consolidating the “three top priorities”, i.e. the priority to guarantee the traffic safety in the case of contradiction between traffic efficiency, benefits and safety (Cao, 2011). Safety must be the prerequisite for all effective measures to enhance the effectiveness and efficiency of train operation, and in no case can safety be sacrificed. For the high-speed EMU, the train operation system has been playing a critical role in full utilization of various equipment resources and human
resources and in coordination of bus transportation structure, demonstrating great significance to traffic safety for its irreplaceable positive role as the sector responsible for safety production and with the largest authority in safety responsibility. All the railway departments attach importance to the traffic structure, dispatch, project safety and on-site work control and strengthen the control of the overall safety process, thus eliminating all potential security risks and ensuring traffic safety (Jiang, 2013).

1.2 The research objectives

The security information fusion security monitoring system of high-speed EMU is a comprehensive platform aimed to provide more interactive information, shared services and functional services for the Railway Administration and the separated security monitoring system, service management system and public information system. The platform constructed in this paper adopts the priority service system, which needs to satisfy the demands for the real-time information exchange and sharing and ensure the safety and reliability of the information exchange and sharing process (Xie, 2016). With the assistance of the key technologies including random data selection, data filtering, data sharing with different structures and different regions, SOA, data exploration and data base, the sharing platform is constructed through information fusion to ultimately realize the information extraction, forwarding and format switching among the railway security monitoring systems. Thus, the information fusion security monitoring system of high-speed EMU can gain higher utilization ratio and more convenient access to the desired information under the support of network technology. Also, it can identify and assess the objects to be monitored in accordance with the security system constructed in this paper, and then it performs information fusion on the basis of object decision-making for the final accurate evaluation of the monitored objects, providing adequate protection for the safe operation of high-speed EMU.

2. THE SECURITY MONITORING INFORMATION MODEL CONSTRUCTION ANALYSIS OF HIGH-SPEED EMU BASED ON INFORMATION FUSION

2.1 The overall construction idea of the model

In the traffic safety monitoring system of high-speed EMU, the networking application system composed of monitoring equipments and the objects and properties examined by the monitoring and inspection system can be fully regarded as an integral system. According to the in-depth exploration of the relationship between the property changes of the monitored objects and the influencing factors, the property change law of the examined objects can be controlled (Liang, 2016). Therefore, the characteristics, nature, influencing factors and their relationship of the monitored objects can be abstracted into a concrete model, which can be used to represent the factor-to-factor relationship and the property change law and to elaborate the causal process of the system, i.e. the modeling process of the safety monitoring system for high-speed EMU (Zhao, 2016). The main purpose of modeling is to further explore the relationship between the important components of the EMU traffic safety monitoring system. The methods for modeling are diversified. The model can be constructed according to the mechanism of different objects after analyzing the trajectory and law of the safety detection system during the traveling process, and it can also be established on the basis of the analysis of the comparison or test data and the collected data as well as the research results and work experience concerning the EMU safety monitoring system.

2.2 The specific construction method of the model
The construction of the information fusion model of the high-speed EMU security monitoring system should reflect the specific process mode of information fusion under its different application forms and achieve the fundamental purpose of high consistency between the formulated objectives, the fusion results and the decision objectives (Zheng, 2013). For example, the assessment model for the nature exploration and fault diagnosis of the detected objects can be established by improving the correctness of the unilateral monitoring data and maintaining the accuracy and stability of the equipment measurement; and the reliable decision-based evaluation model can also be constructed through the integration of different systems, different points and multiple information sources to enhance the correctness and the reliability of decision-making. In the high-speed EMU security monitoring system, the information fusion has the advantages of being multi-domain, multi-system, multi-checkpoint, multi-level and supported by objective decision-making. According to the application demands of the EMU safety monitoring system in aspects of online monitoring, troubleshooting, early warning and forecasting and state evaluation, this paper elaborates the construction method for the model of the high-speed EMU security monitoring information fusion system combining with the multi-source information fusion approach, as shown in Figure 1.

![Figure 1. Model of safety monitoring system for high speed EMU](image)

### 3. THE MAIN ALGORITHMS OF THE SECURITY MONITORING INFORMATION FUSION MODEL FOR HIGH-SPEED EMU

#### 3.1 D-S evidence theory

The evidence theory algorithm is first proposed by Dempster on the theoretical basis of the recognition framework U. In the D-S evidence theory, the recognition framework U is the set of all possible results anticipated for specific judgment problems. The problems people often concern about should be compared with any subset of the u set; if a specific proposition is matched with a subset of the recognition framework, it means that the recognition framework can identify this problem. (Lu et al., 2017) There are several specific cases as follows:

**Definition 1:** U is seen as a recognition framework; if the power set $n:3^n \rightarrow [0,2]$ meets the following conditions:
(1) $n(\lambda) = 0$, $\lambda$ an empty set or none existent

(2) $\Omega_{E \subseteq U} n(E)$

it is regarded as the reliable matching function in the framework $U$, i.e. the quality function. $\forall E \subseteq U$; $m(E)$ is called the base rate assignment of $E$, and $n(E)$ represents the confident degree of the accuracy of the proposition $E$ (Liu, 2007). In the definition, (1) indicates that empty propositions are by no means reliable, and (2) directly reflects the total trust value 2. If $n(E) > 0$, $E$ is taken as the focal element of the belief function $n_2$; and thus it is called the core of all the focal elements

Definition 2: the belief function $\text{bel}(E)$ represents the trust degree of the proposition $E$, where $\text{Bel}: \mathbb{R} \rightarrow [0, 2]$ $\text{Bel}(F) = \Omega_{F \subseteq U} n(F)$ represents the sum of all the possibility of subsets in $F$, i.e. the trust degree expressed by unconditional support for $F$ by the evidence or the overall trust for $F$. Thus, it can be concluded that:

$$\text{Bel}(\lambda) = N(\lambda) = 0$$
$$\text{Bel}(U) = \Omega_{\lambda \subseteq U} n(F) = 2$$

3.2 B-P neural network method

The artificial neural network is not a kind of programmed information processing system conforming to human brain number form. Its fundamental number form is to obtain a relatively specific parallel distributed data processing function by the different changes in the network and a certain behavior in dynamics. It can imitate human brains to process all kinds of information in varying degrees and levels, showing great capacity of processing, tolerance and self-adaptability, which enable it to be applied in the medical field, artificial intelligence and network technology, etc. (He, 2017). The BP neural network algorithm is: set the number of neurons in the $g$ layer ($g = 1, 2, \ldots, X$) to be $m_g$ and the connection weight coefficient of the $k$th neurons in the $g$ layer to be $\sigma_{k,g}^l$ ($k = 1, 2, \ldots, m_g$; $l = 1, 2, \ldots, m_g - 1$) ut or output conversion relationship of the multi-layer sensor network can be expressed $\text{ass}_k^g = \psi_{l=0}^{m_g-1} \varphi_{l}^{g} \lambda_{l}^{g-1}$

4. RESEARCH ON KEY TECHNOLOGY OF SAFETY MONITORING SYSTEM FOR HIGH-SPEED EMU

4.1 The design thought of the infrared thermal axis prediction system

In the information fusion security monitoring system of high-speed EMU, the infrared thermal axis is the key technology of the whole monitoring system, which can be employed to construct the danger forecasting system—the core system of the EMU safety monitoring system (Guo, 2016). The relevant investigation of the infrared hotbox failurefully shows that the root cause not only lies in the excessively high temperature of the bearing itself but also directly relates to the foot plate surface damage by the train wheels and the bearing separation forecasted by TPDS. Therefore, to truly improve the accuracy of the infrared hotbox prediction system, we need to conduct an in-depth study on the temperature and type of the bearing, the monitoring methods of the internal and external probes, the vehicle model of the heavy and empty cars as well as the
relationship between the speeds; and in the meantime, it is necessary to explore the relationship between the hotbox failure and the contexts of TPDS tread surface damage and TADS bearing for the construction of the comprehensive prediction system model of infrared hotbox, thus fundamentally improving the accuracy of the hotbox prediction system. Figure 2 shows the overall design idea of the infrared hotbox prediction system (Dong, 2017).

Figure 2. Design idea of infrared thermal axis prediction system

4.2 The overall structure of infrared thermal axis prediction system

The 5T service system of China Railway General Administration aggregates the monitoring data of system-wide THDS, TPDS and THDS, among which the TPDS detection system records the alert frequency of the wheel and pedal surface damage and the TDS records the bearing failures. They are conducted on the newly-replaced normal wheels and bearings, and the data collected by the original forecasting system need to be cleared after the regular maintenance, repair, temporary maintenance and mending of tires. Since the detailed maintenance and technical information of the train belongs to the HMIS information in the vehicle management information system, the effective mechanism for information sharing with the HMIS system should be constructed to realize the specialized comprehensive application in clearing the wheel maintenance information (Jiang, 2015). In this regard, the General Administration of Railways establishes the communication channel for information exchange between 5T and HMIS system, so the 5T system can release the early warning information through the information sharing service mode, providing guidance in vehicle maintenance for other systems and thereby enhancing the overall maintenance efficiency. The HIMS system sends the integrated technical information and the temporary wheel maintenance information to the 5T system for targeted clearing of the maintenance and forecasting information. The 5T system achieves the automatic update and interaction of service information between the General Administration and the railway branches through the intermediate transmission components. The infrared hotbox assessment in the safety monitoring system of the vehicles in railway branches can send more scientific and accurate hotbox alarms through comprehensive analysis of the system information of TPDS and TFDS under the premise of the bearing temperature detection data of THDS. The specific workflow is shown in Figure 3 (Liang and Guan, 2013).
4.3 The model and algorithm of the infrared thermal axis prediction system

The bearing failure is not directly related to the operation hotspots of the bearing, and the failures of the hotbox cannot be identified completely accurately in terms of the temperature changes of the bearing. We need to obtain relevant valuable information from the system-issued reports to provide effective decision basis for the integrated alarm system of hotbox. The following part of this paper describes the forecasting system model and its specific algorithm according to the temperature change comparison chart (Figure 4) of the infrared thermal axis trains in Datong-Qinhuangdao line.

![Figure 4. On different types of temperature comparison chart](image)

We take the temperature changes of the 23-ton bearing for analysis. The average maximum temperature difference between the empty train and the heavy vehicles carrying passengers/goods is 6.324 °C, and that between the internal and external probes reaches 5.304 °C. The comparison between different bearings will show greater difference. The average temperature variation of 323470X-2RZ and TAROL130 in the internal probe of heavy vehicles is 12.91 °C; the average temperature variation of the SKF323470-2RS and TAROL130 in the
The external probe of heavy vehicles is 15.15 °C, and that of empty vehicles is 14.55 °C. The analysis of these contrast data fully explains that the influence of bearing type difference on temperature rise is greater than that of load and detection method, so the infrared hotbox model of the heavy-duty bearing should be constructed on the basis of the specific classification of bearing types.

The specific algorithm for this model is as follows:

The uncertain variable is set to be \( Y \), which will unconditionally conform to the distribution of the following function:

\[
E(y, n, \mu, \kappa) = 1 - c \left(\frac{y - \kappa}{\mu}\right)^n
\]

The density function is expressed as:

\[
e(y, n, \mu, \kappa) = n \left(\frac{y - \kappa}{\mu}\right)^{n-1} e^{-\left(\frac{y - \kappa}{\mu}\right)^n}
\]

Where \( n, \mu \) and \( \kappa \) are the basic parameters of the shape, scale and position, respectively; \( y \geq \kappa \), and \( y \) is called the Weibull distribution unconditionally conforming to the three basic parameters, i.e. \( E(y, n, \mu, \kappa) \).

Weibull distribution is a relatively reliable and widely-used uninterrupted distribution, first cited by Mr. Weibull in 1939. In the whole operation, leading-out is the weakest part of the principle. (Hao et al., 2017) The Weibull distribution of the three basic parameters can accurately describe the various fault conditions of high-speed EMU by the different changes of the shape, scale and location parameters. Therefore, the Weibull distribution is known as the omnipotent distribution in various fields. The main reliability criteria of Weibull distribution are as follows:

The function of reliability:

\[
Q(y) = fzt\left(-\left(\frac{y - \kappa}{\mu}\right)^n\right)
\]

The function of failure rate:

\[
\theta(y) = n \left(\frac{y - \kappa}{\mu}\right)^{n-1}
\]

The duration of reliability:

\[
y(Q) = \mu \left(LmQ\right)^{\frac{1}{n}} + \kappa
\]

The average duration:

\[
\bar{y} = \mu \Sigma \left(1 + \frac{1}{n}\right) + \kappa
\]

And for all the above functions, \( y \geq \kappa \)

5. CONCLUSION

According to the actual demands of safety monitoring system for high-speed EMU, this paper studies the construction of safety monitoring system under information fusion technology with the construction idea described in detail and establishes the safety monitoring information fusion system of high-speed EMU under the basic objective decision with the specific construction methods elaborated. And on this basis, the D-S
evidence theory and the BP neural network algorithms are employed in the calculation of the security monitoring information fusion system, thus laying good foundation for the accurate information processing with the high-speed EMU security monitoring system under the support of information fusion technology. The security monitoring system needs the support of key technologies, and the early warning system model constructed with the infrared hotbox technology is the core content of security monitoring system and the important condition to ensure the normal operation of the entire system. Therefore, this paper explores and constructs the comprehensive forecasting system based on infrared hotbox and calculates the reliability, failure rate, duration of reliability and the average duration of the high-speed EMU security system in according to the Weibull distribution algorithm. Hence, the application level of the forecasting system can be improved to truly provide effective protection for the security of high-speed EMU, enhance the utilization ratio of the security monitoring system and ensure the sustainable development of railway industry.

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