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Research on applicability test algorithm of wind and rain monitoring equipment of high-speed railway

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Abstract. High-speed railway natural disaster and foreign object intrusion monitoring system is an important technical guarantee for the safe operation of trains. As the basic data source, the reliability and stability of meteorological monitoring equipment is an important prerequisite for the system to play a role. Due to the special measurement principle of meteorological monitoring equipment and the inconvenience of equipment inspection along the high-speed railway, there is currently a lack of flexible and efficient applicability inspection algorithms for equipment failure and monitoring data distortion. Based on the measurement principle of the wind and rain monitoring equipment, this paper analyzes the causes of data distortion and abnormal data characteristics, then puts forward the applicability test algorithm of high-speed railway wind and rain monitoring equipment. Through data analysis methods such as correlation test and difference test, the applicability test of anemometers was carried out. The top-cover piezoelectric rain gauge inspection equipment was developed, and the applicability test of microwave rain gauge was carried out by means of data comparative analysis. Finally, we tested the algorithm in actual high-speed rail lines, and the results show that the proposed algorithm can effectively identify the monitoring equipment with poor adaptability.

1 Introduction

At present, the natural disaster and foreign object intrusion monitoring system has been simultaneously established in high-speed railways, which can monitor and alarm the disasters such as wind, rain, snow, and foreign object intrusion, and provide suggestions on speed limit disposal for the dispatching command. Considering the particularity of high-speed railway wind and rain monitoring equipment, the system mainly uses ultrasonic anemometers, piezoelectric rain gauge, microwave rain gauge, and other non-contact sensors. In the operation process, the following problems are exposed: the distortion of wind and rain

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monitoring data, the lack of maintenance technology, and the high cost of the applicability test through the laboratory. Based on the measurement principle of high-speed railway wind and rain monitoring equipment, this paper analyzes the causes of data distortion and abnormal data characteristics. At the same time, we put forward the applicability test algorithm of wind and rain monitoring equipment. Through data analysis methods such as correlation test and difference test, the applicability test of anemometers was carried out. The top-cover piezoelectric rain gauge inspection equipment was developed, and the applicability test of microwave rain gauge was carried out by means of data comparative analysis. The proposed method can quickly screen the equipment with poor applicability, which avoids the low efficiency, long period, and high cost of dismantling all the equipment for inspection.

2 Research status of applicability testing algorithm of wind and rain monitoring equipment

The JR East Japan disaster prevention system uses anemometers of propeller type and rain gauges of tipping bucket type to monitor the wind and rain data along the line. They use the inspection technology of the meteorological equipment to ensure the quantity. German high-speed railway adopts LUFFT ultrasonic anemometers, and the applicability test of equipment adopts comparison technology in the natural environment.

Zhao et al. [1] proposed an outlier wind speed detection method based on a neural network model. Yong Tang et al. [2] designed a low-cost portable miniature low-speed wind tunnel for the WXT520 ultrasonic anemometers. Shiru Deng et al. [3] compared the monitoring data of a conventional anemometer with a CSAT3 3-d ultrasonic anemometer and verified the accuracy of monitoring data and equipment reliability. Wind cup anemometer is widely used in the domestic meteorological field to measure wind speed. Through the wind tunnel simulation of different strengths of the standard wind speed, the anemometer applicability test is achieved. Salmi et al. [4] conducted the applicability test by analyzing the measurement differences of the piezoelectric rain gauge, tipping bucket rain gauge, and weighing rain gauge under different rainfall grades. Yaqun Li et al. [5] proposed an accuracy and reliability test method of non-contact rain gauge by analyzing the integrity, consistency, and failure rate of experimental data in an artificial rainfall environment with an orthogonal test method.

Aiming at ultrasonic anemometer widely used in high-speed railways, a lightweight applicability detection method based on data analysis is proposed. For the piezoelectric rain gauge and microwave rain gauge, we developed piezoelectric rain gauge verification equipment. At the same time, a microwave rain gauge applicability test method based on a data comparative analysis is proposed.

3 Applicability test algorithm for wind and rain monitoring equipment of high-speed railway

3.1 Anemometer

On account of wind's local characteristics and the correlation and comparability of two anemometers' monitoring data, two data analysis methods of correlation and difference are combined to verify ultrasonic anemometer.

The algorithm flow of the anemometer applicability test is shown in Fig. 1. The wind speed data of the two anemometers in the last 4 hours were extracted to calculate the minute average wind speed data. The correlation and difference analysis and test were conducted for the minute average wind speed data of the two anemometers.

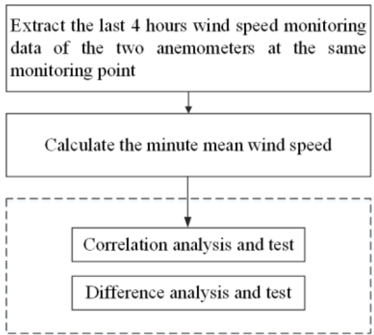

Fig. 1. Flow chart of anemometer adaptability test algorithm.

When the correlation test p-value is lower than 0.05, the correlation coefficient is higher than 0.5 and the different test p-value is higher than 0.05, the measurement data of the two anemometers are accurate. Otherwise, one or two devices with inaccurate measurement data exist at the monitoring point.

3.1.1 Correlation analysis and test

(1) Correlation analysis.

The correlation coefficient is a statistical indicator reflecting the closeness between variables. The value ranges from -1 to 1. ‘1’ indicates that the two variables are completely positively correlated, ‘-1’ indicates that the two variables are completely negatively correlated, and ‘0’ means that the two variables are not correlated.

The calculation formula of the correlation coefficient is as follows:

$$r_{xy} = S_{xy}/S_xS_y \tag{1}$$

where r_{xy} represents the sample correlation coefficient, and S_{xy} represents the sample covariance. S_x represents the sample standard deviation of the anemometer x, and S_y represents the sample standard deviation of the anemometer y.

If the correlation coefficient is close to 0, it can be judged that there is an anemometer with poor applicability at the monitoring point.

(2) Correlation test.

Assume n pairs of wind data (x_1, y_1), (x_2, y_2),..., (x_n, y_n), if $\forall j > i$, $i, j = 1,2,..., n$, $(x_j - x_i)\times(y_j - y_i)>0$, so (x_i, y_i) and (x_j, y_j) are identical, or they change in the same direction. Otherwise, the number pairs are uncoordinated.

All the possible data logarithms have $n(n-1)/2$ pairs. We use N_c to represent the number of pairs in the same direction, N_d to represent the number of pairs in the opposite direction, so $N_c + N_d = n(n-1)/2$.

The correlation coefficient statistics is as follows, which is defined by the average difference between N_c and N_d:

$$\tau = (N_c - N_d)/[n(n-1)/2] = 2S/[n(n-1)/2] \tag{2}$$

where $S = N_c - N_d$, $-1 \le \tau \le 1$.

• If all the pairs are consistent, then $N_c = n(n-1)/2$, $N_d = 0$, $\tau = 1$, indicating the data of two anemometers is positively correlated.

• If all the pairs are opposite, then $N_c = 0$, $N_c = n(n-1)/2$, $N_d = 0$, $\tau = -1$, indicating the data of two anemometers is negatively correlated.

• $\tau = 0$ denotes a similar number of the same or opposite direction in the data, with no apparent trend.

Assume that x_i has been arranged from small to large, so the synergy problem is transformed into the rank change problem of y_i.

$$p_i = \Sigma_{j>i} I_{(d_j > d_i)}, i = 1,2,..., n \tag{3}$$

$$q_i = \Sigma_{j>i} I_{(d_j < d_i)}, i = 1,2,\ldots, n \tag{4}$$

We make $P = \sum_{i=1}^{n} p_i$, $Q = \sum_{i=1}^{n} q_i$, then the estimate of τ statistic is:

$$K = (P\text{-}Q)/[n(n\text{-}1)/2] \tag{5}$$

Then for the correlation test problem:

H_0: Sequence X has no correlation with sequence Y.

H_1: Sequence X has a correlation with sequence Y.

When $k \geqslant C_\alpha$, H_0 is rejected, and when $k < C_\alpha$, H_0 is accepted. The critical value C_α satisfies $p(k \geqslant C_\alpha) = \alpha$.

3.1.2 Difference analysis and test

The algorithm uses the Wilcoxon sign rank test method to check whether there is poor applicability equipment between two anemometers at the same monitoring point. The basic idea is as follows:

• Subtract the values of the corresponding positions of the samples in group 1 from the values of the samples in group 2. If the difference is positive, it is marked as a positive sign, and if it is negative, it is marked as a negative sign.

• The absolute value of the difference was sorted in ascending order, and the rank of the variable was calculated. The sum of the positive rank W_+ and the sum of the negative rank W_- were respectively calculated.

• The original hypothesis H_0 is that there is no significant difference in the distribution of the monitoring data of the two anemometers. When the null hypothesis is true, W_+ and W_- are not very different. However, when W_+ and W_- differ greatly, the truth of the null hypothesis should be doubted.

• Calculate the test statistic $W = min(W_+, W_-)$. According to the W value, the distribution table of the Wilcoxon sign rank test is used to obtain the p-value under the null hypothesis.

The p-value is the probability of the sample observation or more extreme result if the null hypothesis is true.

If the p-value is very small, it indicates that the probability of this happening is very small and the null hypothesis can be rejected. The smaller the p-value is, the more sufficient the reason for rejecting the null hypothesis is.

3.2 Rain gauges

In our research work, three abnormal data types of rain gauges caused by equipment failure were found, which were abnormal data loss, equipment disconnection, and data jump over the range. The flow chart of the rain gauges applicability test is shown in Fig. 2.

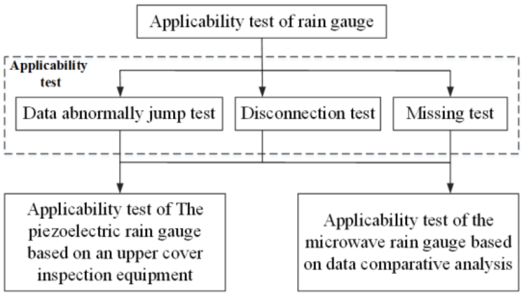

Fig. 2. Flow chart of the rain gauges applicability test algorithm.

Due to the rain gauge uploading rainfall data once 1 minute, the abnormal missing test is proposed by detecting whether the time of uploading data is continuous. When the equipment is disconnected, the system writes the self-defined disconnected code into the rain data. Loss detection is carried out by detecting whether loss codes appear in rainfall data. By detecting whether the rainfall difference of adjacent 2 minutes is greater than the normal jump threshold, the jump detection that is larger than the range is carried out.

3.2.1 The piezoelectric rain gauge

The top-cover piezoelectric rain gauge inspection equipment uses the electromagnetic actuator to generate the impact force at the inductive position of the rain sensor to simulate the impact of raindrops. The electromagnetic coil is controlled by an electrical pulse to produce a sequence of one strike per second. All the electronics are on top of the tester. The middle part is a zero air chamber, in which the electromagnetic coil is located. The bottom is used to mount and secure the tester above the sensor while sealing the tester to prevent wind from entering the zero air chamber. The device can set the intensity of the attack, the working time, and the working cycle.

The output voltage data of the piezo-type rain gauge under test should be 95%~105% of the rated output voltage when simulated rainfall by the upper cover rainfall verification equipment. Each rain gauge should be checked 3 times.

In the three tests, if the output voltage is 95%~105% of the rated output voltage, pass the test.

3.2.2 Microwave rain gauge

A tip bucket rain gauge is installed near the monitoring point to verify the applicability by analyzing and comparing the data of microwave and tip bucket rain gauge.

After natural rainfall, the data error between the microwave and the tip bucket rain gauge should not be greater than 0.5 mm (when the rainfall is ≤10 mm) and 8% (when the rainfall is >10 mm).

4 Experiments

4.1 Actual high-speed railway test of the anemometer

46 wind monitoring points of a certain line were selected, and the continuous wind speed data of 2 anemometers were collected on the same monitoring points successively.

The inspection results are shown in Table 1, where the numbers in bold denote abnormal indicators.

Table 1. Applicability test results of actual high-speed railway.

Monitoring point	Correlation coefficient	Correlation test p-value	Difference test p-value	Test results
1	0.879	0.000	0.547	normal
2	0.730	0.000	0.927	normal
3	**0.006**	**0.267**	0.038	**abnormal**
4	0.839	0.000	**0.000**	**abnormal**
5	0.911	0.000	**0.000**	**abnormal**
……				
46	0.849	0.000	0.057	normal

The wind tunnel test results are consistent with the results of the proposed algorithm, indicating that the proposed algorithm can effectively detect the monitoring points with poor applicability.

4.2 Piezoelectric rain gauges applicability test

Mount the verification device vertically to the top of the rain sensor so that the bottom touches the sensor surface. The verification results show that the output voltage of the two piezoelectric rain gauges is in the normal range.

Table 3. Adaptability test results of rain gauges.

Monitoring point	Standard Values (mV)	Test Values (mV)	Standard deviation	Error	Test results
1	2750	2771	98	0.76%	normal
2	2750	2835	58	3.09%	normal
3	2750	2725	53	-0.91%	normal

4.3 Microware rain gauges applicability test

During the test, a total of 11 rainfall fields were collected, and the data records of 2 rain gauges under each rainfall condition are shown in Fig. 3.

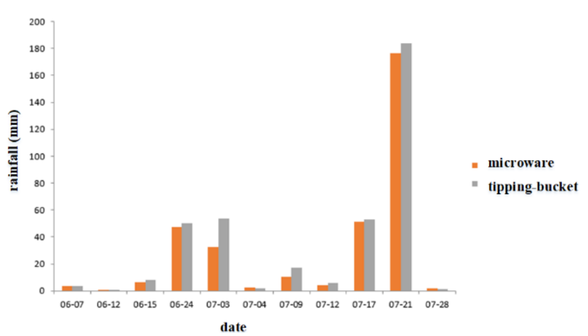

Fig. 3. Applicability test of the microwave rain gauge.

In the comparison test between the two rain gauges, 6 rain cases with less than 10mm, in which the maximum deviation is -1.8mm. 5 rain cases with more than 10mm, and the maximum deviation is -39.4%. It is considered that the measurement data of the microwave rain gauge is not accurate.

5 Conclusion

Based on the high-speed anemometer, piezoelectric/microwave rain gauge measuring principle and data characteristics, this paper proposed the anemometer applicability test algorithm based correlation and difference analysis, the top-cover piezoelectric rain gauge verification scheme, and microwave rain gauge applicability test scheme, which plays an important role in guaranteeing the applicability of wind and rain monitoring equipment.

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