Research on Fault Diagnosis Algorithm of Subway Vehicle Door System Based on Multi-stage Feature Fusion of Vibration Signals

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Introduction

The subway vehicle door system is one of the most crucial features of urban rail transit systems. Due to increased density and switching frequency of the door, its load-carrying transmission mechanism is more prone to failure or damage than the other components [1]. A quick and precise evaluation analysis of its health status is a more effective way of removing hidden flaws and increasing the door system's safety and dependability. Thus, we address the problem of frequent failure in the door system, begin with vibration signal analysis in accelerated life testing, and investigate the method of effective health status assessment of the mechanism from the perspective of multi-stage vibration signal analysis to ensure the accuracy and efficiency of the diagnostic process and results.
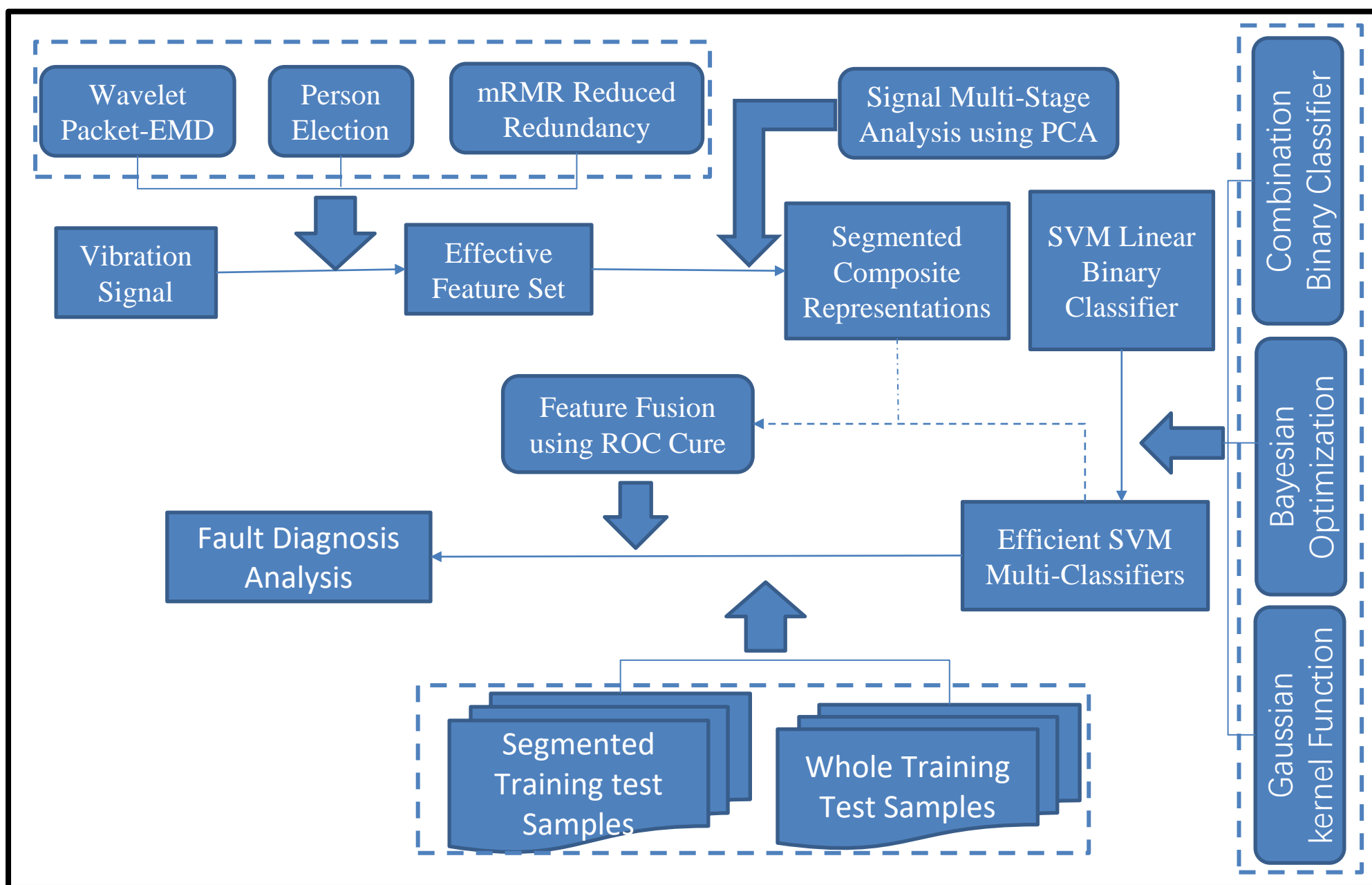
Methodology

Figure 1. The technology roadmap

We used the Peron coefficient method and mRMR algorithm for effective feature set construction based on wavelet packet EMD noise reduction, which is efficient in avoiding information catastrophe as well as ensuring high correlation and low redundancy of the feature set [2]: $\max \varphi(D,R) = D - R$

- Where: D is the correlation, R is the redundancy of features, and the difference in mutual information φ is to achieve a comprehensive evaluation of the effectiveness of the feature parameters.

By analyzing the signal phases of the door system, we segmented the vibration signals for comparative analysis and used principal component analysis(PCA) to obtain segmented composite representations of the quantities to extract the complete characteristic parameters that identify the mechanism's motion status thoroughly and accurately [3]。

From the characteristics of linear distribution of samples and the efficiency and accuracy of the model, we used Gaussian kernel function, Bayesian hyper-parameter optimization algorithm and combination binary classification (OvR) methods to construct an efficient SVM multi-classifier [4], and the fused segmented composite representations obtained by ROC curve analysis are fed into this multi-classifier with the training test samples to obtain the final good classification results for fault diagnosis [5].

Results

◆ Pre-processing for Noise Reduction

EMD algorithm combined with Wavelet Packet can effectively avoid the phenomenon of modal aliasing and realize effective noise reduction. As illustrated in figure 2, the noise effect component is decreased with wavelet packet EMD noise reduction, while the signal's original trend is preserved.
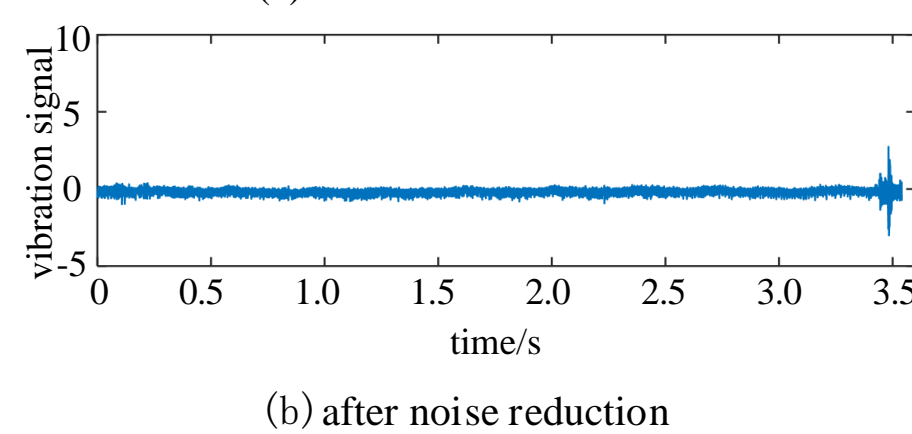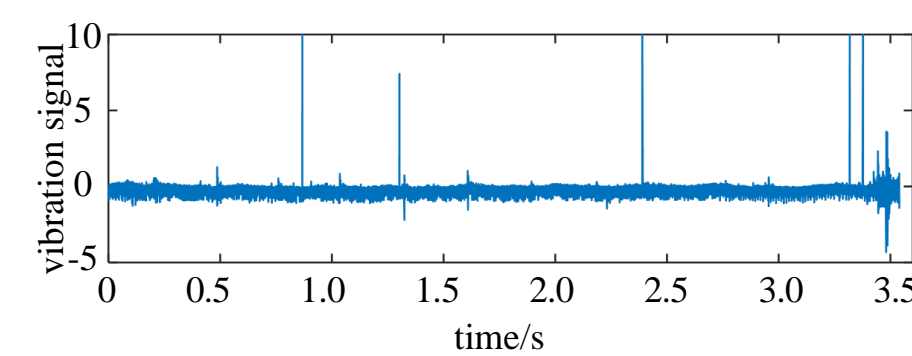

Figure 2. Comparison of time-domain signals before and after noise reduction

◆ Effective feature construction

The distribution of results based on mRMR and Pearson Analysis is shown in figure 3. The feature set value has the greatest worth when it is introduced for the fourth time. So, "standard deviation, peak, root-mean-square of frequency, waveform factor, and margin factor", a feature set of the four parameters has the best status response capacity.
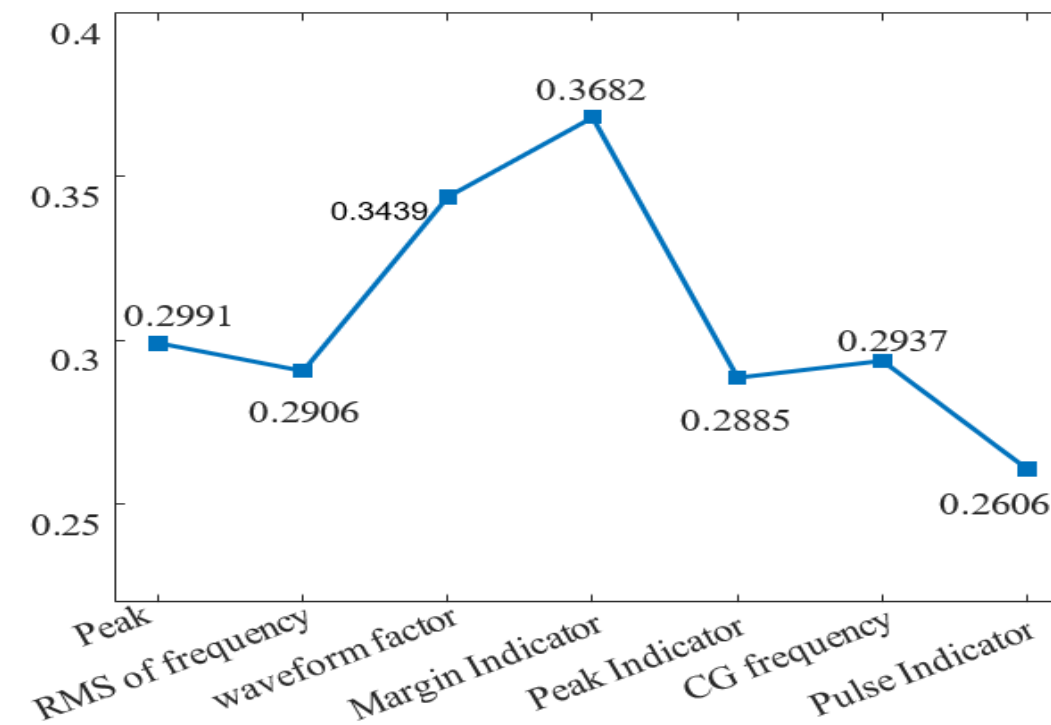

Figure 3. Variation of mutual information difference of feature parameter set.

Figure 4. Curve diagram of door movement during the opening process.

◆ Signal segmentation

As shown in figure 4, combining the opening motion curves of the door system, the motion process of its mechanism may be separated into three stages: the accelerated start-up phase, the smooth-running stage, and the stopping stage.
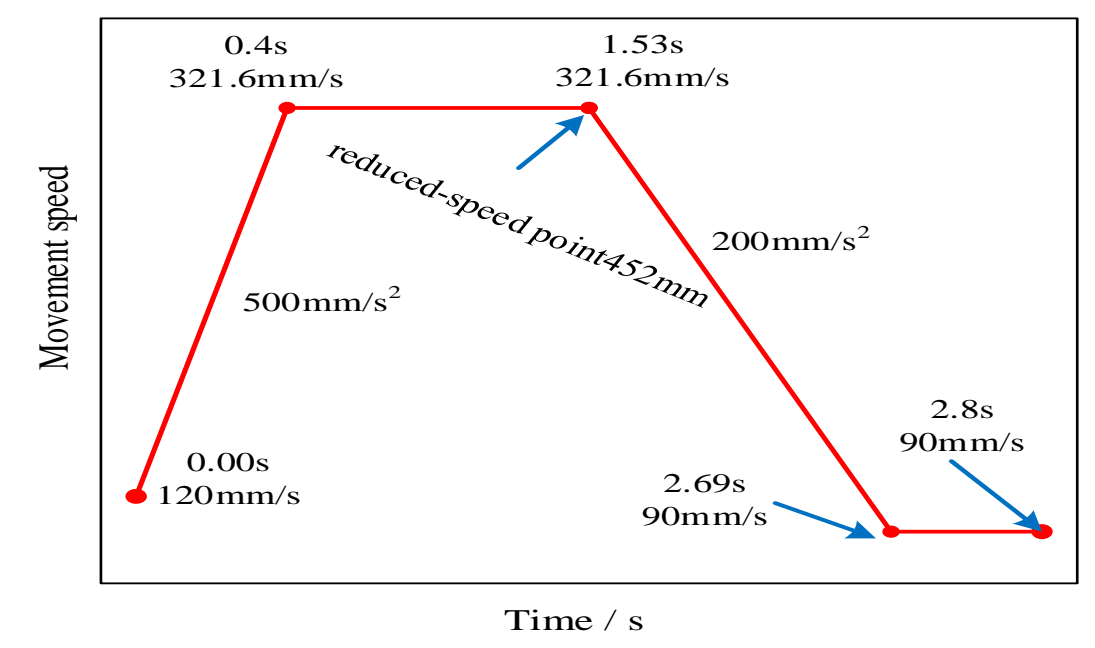
◆ Principal Element Feature Fusion

As illustrated in table 1, A-segment signals lack effective classification ability, B-segment signals for pulley faults have good characteristics to reflect the ability, and C-segment signals for coupling faults and normal operating conditions have good characteristics to reflect the ability.

Table 1. AUC values for each model classification

Segmental signal	Type of organizational status		
	Coupling Failure	Pulley failure	Normal status
A-segment signals	0.563	0.554	0.586
B-segment signals	0.679	0.863	0.713
C-segment signals	0.882	0.671	0.907

According to the PCA, first B-segment principal element, first and second C-segment principal elements are the final-integrated status feature quantities set, α. Meanwhile, to ease the comparison of diagnostic accuracy before and after segmentation, the status feature set for unsegmented signals, β, was obtained by the same way

◆ Fault diagnosis classification effect analysis

α and β are each input to the SVM classifier, and the same data are used to train and test the classification model, as shown in table 5 and table 6. During testing, each classification function value is generated independently for each sample in the test set. The final comparison impact is illustrated in figure 7 and figure 8 and the classification accuracy is 95.63 percent and 89.38 percent, respectively, an improvement of 6.25 percent.
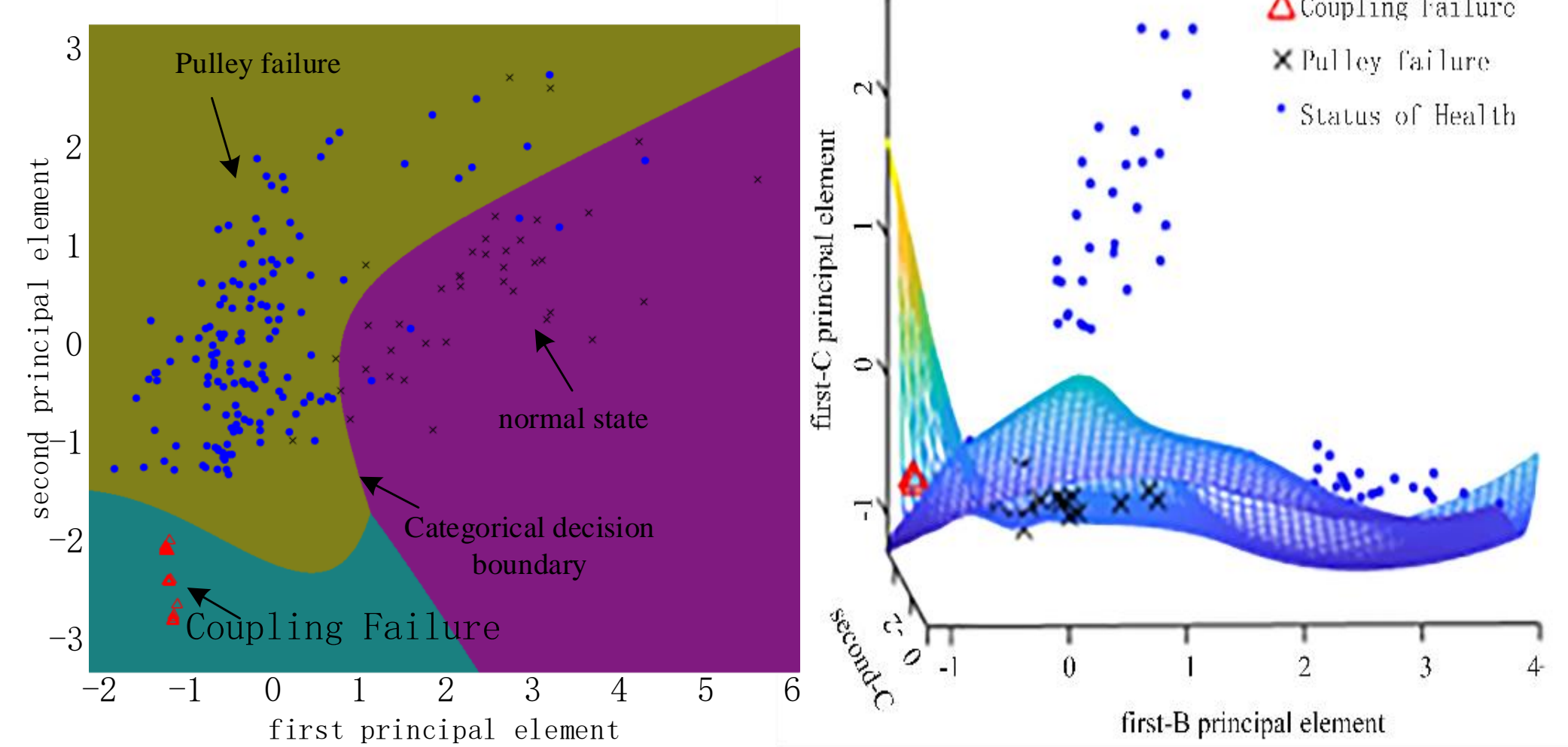

Figure 5. Unsegmented SVM classification effect

Figure 6. Signal segmentation SVM classification effec

Conclusions

➢ **Conclusions** :
- EMD algorithm combined with Wavelet Packet avoids the phenomenon of signal mode mixing.
- Algorithms such as Person, mRMR, and PCA are used to extract comprehensive features that can effectively characterize the status of the mechanism.
- SVM Multi-classification Model using the combination binary classifier of OvR is constructed based on the Bayesian hyper-parameter optimization algorithm , and the classification effect of the assessment model is effectively improved by the analysis method of multi-stage principal element feature fusion.

References
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