Driving collision detection method based on VMD-KICA

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Abstract: With the rapid development of China's transportation, higher requirements are put forward for the handling capacity of traffic accidents. Therefore, it is of great practical significance to study the effective monitoring methods of high-speed traffic accidents for timely guiding the traffic and saving the lives of the injured. The VMD is used to decompose the vehicle vibration signal, and the cross-correlation coefficient is used as the index to screen the components, and the KICA algorithm is used to extract the components of the screened component matrix, so as to further eliminate the environmental noise. The signal is recombined by the denoised components to highlight the time-domain statistical characteristics of the signal. The feature vector based on time-domain statistical parameters is constructed, and the recognition model is built by using the support vector mechanism optimized by genetic algorithm. The experimental results show that the accuracy of the method for vehicle driving state can be 95.5%.

1. Introduction
By the end of 2020, the number of vehicles in China is about 372 million, including more than 3 million in Beijing, Chengdu and other 12 cities. China has the largest number of vehicles in the world, while the number of vehicles is still increasing. The rapid increase of vehicles not only causes travel pressure to the society, but also increases the probability of traffic accidents, thus increasing the hidden danger of travel\textsuperscript{[1]}. Therefore, it puts forward higher requirements for the handling capacity of traffic accidents. At present, the highway monitoring is mainly based on video monitoring, which is more mature in technology. However, when the visibility is poor, such as rain, snow or night, the accuracy rate has
declined, and the economic cost is high, so it is difficult to fully control. Based on the above situation, this paper proposes a method to distinguish the normal driving and collision of vehicles by detecting the vibration signal generated in the process of vehicle driving, and carries out the experimental verification.

The key link of vehicle driving state discrimination is how to extract effective features under the interference of environmental noise. The collected vehicle driving vibration signal contains a variety of frequency components, which are non-stationary random signals. Therefore, it is difficult to extract them completely by using a single method, such as low-pass filtering or high pass filtering and other traditional noise reduction methods. Although the noise is filtered, the feature information in the target signal is defective, which reduces the accuracy of the subsequent recognition of vehicle driving state, so it is not desirable. Therefore, it is necessary to introduce an adaptive noise reduction method for non-stationary signals.

In view of the nonlinear problem caused by multi-component in mechanical vibration signal, EMD algorithm is used to decompose the vibration signal in literature \[2\], and FFT is used to get the frequency spectrum to extract the characteristic frequency. However, this method has the problem of large mode aliasing. Although it is widely used in engineering, it lacks strict theoretical derivation.

Aiming at the non-stationary and non-linear problem of vibration signal of vibration rolling bearing in literature \[3\], singular entropy, energy entropy and displacement entropy are extracted from decomposed signal by using information fusion theory, which are used as feature vectors to build fault recognition model. However, there are only three dimensions, which can not be used to analyze the signal comprehensively.

In order to solve the above problems, this paper proposes a method of vibration signal recognition based on VMD-KICA. The VMD algorithm with good properties is used to decompose the signal adaptively, and several eigenmode functions are obtained. The components are filtered by correlation coefficient, and the components are de-noising by KICA algorithm. After the reconstruction of each component, the adaptive filtering is completed. The features are extracted from multiple scales, and the feature vectors are constructed to complete the recognition.

2. Algorithms

2.1. VMD

VMD (variable mode decomposition) is a method proposed by Dragomiretskiy et al in 2014 to decompose the signal into eigenmode functions of different frequencies by iteratively searching the variational model \[4\]. Compared with EMD, LMD, ITD and other methods, VMD not only further improves the problem of mode aliasing, but also has more rigorous mathematical proof process and noise robustness. The solving process of VMD is mainly divided into two parts: establishing variational model and solving variational model.

In order to make the decomposition process more rigorous, VMD defines the intrinsic mode function as AM-FM signal:

\[ u_k(t) = A_k(t)\cos(\phi_k(t)) \quad (1) \]

In equation (1), \( A_k(t) \) represents the instantaneous amplitude of the signal, \( \phi_k(t) \) represents instantaneous phase, it is assumed that the signal consists of multiple components \( u_k(t), k = 1, 2, 3 \ldots K \), the center frequency of each component is \( \omega_k, k = 1, 2, 3 \ldots K \). The algorithm of VMD is as follows:

Algorithm: VMD

Step (1) IMF initialization and Hilbert transform. Initialization of \( u_k(t) \) and Hilbert transform to get the analytic signal:

\[ U_k(t) = \delta(t) + \frac{j}{\pi t} * u_k(t) \quad (2) \]
Step (2) Frequency band benchmarking:

\[
[(\delta(t) + j \frac{\omega}{\pi t}) * u_k(t)] e^{-j \omega t}
\]  

(3)

Step (3) Establish the constrained variational model:

\[
\min_{\{u_k\}, \{\omega_k\}} \left\{ \sum_{k=1}^{K} \mathbb{E} \left[ |(\delta(t) + j \frac{\omega}{\pi t}) * u_k(t) |^2 e^{-j \omega t} \right] \right\}
\]

subject to \( \sum_{k=1}^{K} u_k(t) = x(t) \)

(4)

Step (4) Remove the constraints of the model:

\[
L(\{u_k(t)\}, \{\omega_k\}, \lambda(t)) = \alpha \sum_{k=1}^{K} \mathbb{E} \left[ |(\delta(t) + j \frac{\omega}{\pi t}) * u_k(t) |^2 \right] + \left\| x(t) - \sum_{k=1}^{K} u_k(t) \right\|^2 + \left\langle \lambda(t), x(t) - \sum_{k=1}^{K} u_k(t) \right\rangle
\]

(5)

Step (5) Solving unconstrained variational model:

\[
\hat{u}_k^{\omega}(\omega) = \frac{\hat{x}(\omega) - \sum_{k=1}^{K} \hat{u}_k(\omega) + \hat{\lambda}(\omega)}{1 + 2\alpha (\omega + \omega_k)^2}
\]  

(6)

\[
\hat{\delta}_k^{\omega}(\omega) = \frac{\int_{\omega}^{\infty} \omega |\hat{u}_k(\omega)|^2 d\omega}{\int_{\omega}^{\infty} |\hat{u}_k(\omega)|^2 d\omega}
\]  

(7)

\( K \) can be obtained by inverse Fourier transform.

2.2. KICA
ICA combines principal component analysis and factor decomposition, and its principle is as follows:
Suppose the signal observation matrix is \( X = [x_1, \ldots, x_n]^T \). In ICA theory, the observation matrix can be obtained by linear transformation of several independent variables \( S = [s_1, \ldots, s_n]^T \):

\[
S = W^T X
\]  

(8)

By solving the optimal unmixing matrix \( W_{\text{best}} \), the optimal estimation matrix \( S_{\text{best}} \) of the independent source signal is obtained, and the independent variables in the observation matrix can be separated.

Compared with PCA, ICA has excellent performance in the analysis of non Gaussian problems, but as a linear transformation, many objects in practical application are nonlinear problems. For example, in this paper, the vehicle vibration signal is taken as the research object, in order to solve this problem, the kernel function is introduced into ICA analysis, Through the mapping of nonlinear function, the problem is transformed into the solution of the kernel regularization correlation coefficient in the reconstructed Hilbert space, which is called KICA(Kernel Independent Component Analysis) algorithm.[5] The problem is transformed into linear separable, and the problem of too large calculation caused by the disaster of dimension in high-dimensional space is avoided.

3. Results
The signal shown in Figure 1 is the signal of normal driving and collision. The data comes from Shanghai
motor vehicle testing and certification technology research center. The company has the national recognized motor vehicle testing qualification and undertakes the collision testing experiments of several famous automobile manufacturers. Figure 2 is the decomposition diagram of the signal passing through VMD in normal driving, and figure 3 is the decomposition diagram of the signal passing through VMD in collision.

Figure 1 original signal

components of normal driving signal

Figure 2 components of normal driving signal
In this paper, the cross-correlation coefficient is selected as the index to filter the decomposed signal, and the components with larger correlation number with the original signal are selected to reconstruct the signal, and the main components of the signal are extracted to realize adaptive filtering and highlight the time-domain scale characteristics of the signal.

Among the ten components decomposed, six main components are selected to reconstruct the signal. As shown in Table 1, among the components of normal driving signal, the first six components have larger correlation coefficient with the original signal. As shown in Table 2, among the collision signals, IMF1, IMF2, IMF3, IMF5, IMF8 and IMF9 have larger correlation coefficients.

Figure 3 Components of collision signal

![Figure 3 Components of collision signal](image)

Table 1 Cross correlation coefficient between IMF of normal driving signal and original signal

| IMF  | IMF1 | IMF2 | IMF3 | IMF4 | IMF5 |
|------|------|------|------|------|------|
| IMF  | 0.844| 0.478| 0.227| 0.096| 0.342|
| IMF  | IMF6 | IMF7 | IMF8 | IMF9 | IMF10|
| correlation number | 0.131| 0.043| 0.035| 0.042| 0.037|

Table 2 Cross correlation coefficient of each IMF of collision signal and original signal

| IMF  | IMF1 | IMF2 | IMF3 | IMF4 | IMF5 |
|------|------|------|------|------|------|
| IMF  | 0.836| 0.258| 0.227| 0.181| 0.342|
| IMF  | IMF6 | IMF7 | IMF8 | IMF9 | IMF10|
| correlation number | 0.162| 0.121| 0.251| 0.240| 0.207|

Fig. 4 and Fig. 5 respectively show the components processed by KICA, which are used to reconstruct the signal to eliminate the associated environmental noise and highlight the time-domain scale characteristics of the signal. In the literature, KICA algorithm is used to decompose the signal, which can eliminate the residual noise in the signal and further improve the phenomenon of mode aliasing. However, in this experiment, although the noise is eliminated, the correlation coefficient between the components is enhanced. Through reading the literature and analyzing the experimental content, the signal in the literature is a periodic signal, in the acquisition environment, the acquisition device is placed on the mechanical surface, and the signal propagation distance is very short, so the
collected signal is almost not affected by the propagation medium and distance, and the environmental noise can be ignored, so it is an ideal periodic signal. The vehicle driving vibration signal collected in this paper is mainly affected by three aspects: the internal structure of the vehicle, the vibration of the vehicle. It includes the influence of resonance of internal components caused by the change of vehicle driving state; Compared with the mechanical surface, the energy absorption of the transmission medium is relatively loose; With the increase of the propagation distance, the signal decays exponentially and is accompanied by strong environmental noise. Under the action of various factors, the collected vehicle vibration signal is aperiodic, and the environmental noise is randomly distributed in the frequency domain, which is close to white noise. The correlation between each component is enhanced, so the results are different from those in the literature.

According to the statistical characteristic quantity of vehicle vibration signal, the driving state of vehicle can be distinguished. The time domain characteristic quantity analysis is to calculate the statistical parameters of signal and take them as the characteristic vector, so as to complete the identification of accident signal. The time domain scale parameters used in this experiment include maximum, peak, kurtosis, pulse, root mean square, margin, mean and slope.

![Figure 4 normal driving signal from KICA](image)

![Figure 5 collision signal from KICA](image)
In this paper, SVM is used to build the recognition model, and genetic algorithm is used to optimize the model. Ten experiments are carried out on SVM with or without genetic algorithm, as shown in Figure 6. Before optimization, the recognition rate on the test set is about 89%, and the highest is 91.5%. After optimization, the recognition rate is about 94%, and the highest is 95.5%. Soft interval support vector machine has high accuracy in target recognition of vehicle vibration signal and accident signal. Genetic algorithm can improve the accuracy of SVM optimization.

4. Conclusions
1. Aiming at the problem that the effect of traditional filtering algorithm is not ideal due to the non-linear and non-stationary nature of vehicle driving vibration signal, the vmd-kica algorithm can complete the adaptive decomposition of the signal and extract the principal component to complete the adaptive filtering based on the signal itself.
2. The time domain statistical parameters of vehicle vibration signal contain rich feature information. The recognition rate can reach 95.5%.

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