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Research on Water Supply Pipe Leakage Diagnosis Algorithm

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Abstract: In this paper, we address the difficult problems in pipeline leakage diagnosis and investigate the leakage diagnosis algorithm based on vibration signal analysis with pipeline vibration signal as the basis. The SSA-VMD algorithm is used to decompose the pipeline vibration signal and conduct comparative experiments. The results of the comparison experiments show the superiority of the SSA-VMD algorithm. Then the decomposed IMF components are feature extracted to construct single feature vectors and then combined feature vectors. Finally, the support vector machine is optimized using the improved grid search method, and comparative experiments are conducted for the single feature vector and the combined feature vector, respectively. The experimental results show that the support vector machine optimized by the improved grid search method has a higher recognition accuracy.

Keywords: Leakage diagnosis, Water supply lines, SSA-VMD, Vibration signal

1. Introduction

Leaks occur in water supply pipes for various reasons[1-5]. There are various methods for diagnosing leaks in water supply pipes, such as numerical modeling methods, data-driven methods, thermal infrared procedure methods, and vibration signal-based diagnostic methods. However, the model parameters of the numerical modeling method are difficult to obtain, the data-driven method requires the use of a large number of pipeline monitoring equipment, and the thermal infrared imaging method is limited by the weather.

The vibration signal-based pipe leakage diagnosis has a wide range of application, high diagnostic accuracy and speed, and the related algorithm for pipe vibration signal has certain noise suppression capability, so the vibration signal-based method has become a key research area for water supply pipe leakage diagnosis. Yang Jin et al[6] used a neural network algorithm to diagnose pipeline leaks by correlating pipeline vibration signals and using approximate entropy as a feature of the leaky vibration signals into a neural network. El-Zaha et al[7,8]experimentally demonstrated a real-time monitoring system for pressurized water pipeline networks based on wireless accelerometers. They used the collected signals to establish threshold monitoring

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indicators for leak diagnosis to achieve leak diagnosis. Chuanqiang Xia et al[9]used variational modal decomposition to decompose the vibration signal, extract the features and input them into a support vector machine to diagnose the pipe leakage.

2. Algorithm Research

2.1 Research on Variational Modal Processing Algorithm for Vibration Signal

Pipeline vibration signal is a non-smooth, non-linear mixed signal. The variational modal decomposition algorithm is a signal decomposition algorithm with high applicability and stability, the pipe vibration signal can be effectively decomposed to facilitate the construction of feature vectors[10]. Sparrow search algorithm is a new type of intelligent optimization algorithm, the algorithm solves for the global optimization problem[11,12], and the sparrow search algorithm can well avoid the problem of the algorithm falling into local optimum.

The location update of sparrow discoverer, joiner, and alerter can be expressed as:

$$x_{i,j}^{t+1} = \begin{cases} x_{i,j}^{t} \cdot \exp\left(-\dfrac{i}{\alpha, iter_{\max}} \right), & R_2 < ST \\ x_{i,j}^{t} + Q \cdot L, & R_2 \geq ST \end{cases} \tag{1}$$

$$x_{i,j}^{t+1} = \begin{cases} Q \cdot \exp\left(\dfrac{x_{\text{worst}}^{t} - x_{i,j}^{t}}{i^2} \right), & i > \dfrac{n}{2} \\ x_{p}^{t+1} + \left| x_{i,j}^{t} - x_{p}^{t+1} \right| \cdot A^{+} \cdot L, & \text{Other} \end{cases} \tag{2}$$

$$x_{i,j}^{t+1} = \begin{cases} x_{\text{best}}^{t} + \beta \cdot \left| x_{i,j}^{t} - x_{\text{best}}^{t} \right|, & f_i > f_g \\ x_{i,j}^{t} + K \cdot \left(\dfrac{\left| x_{i,j}^{t} - x_{\text{worst}}^{t} \right|}{\left(f_i - f_w \right) + \varepsilon} \right), & f_i = f_g \end{cases} \tag{3}$$

In this paper, the variational modal decomposition algorithm is combined with the sparrow search algorithm to apply, Sparrow Search Algorithm-Variational Mode Decomposition (SSA-VMD) is used to optimize the number of modal decompositions and the number of penalty factors of the variational modal decomposition. Assuming that the time signal is expressed as a function of x(m). First, the Hilbert demodulation transform of signal x(m) is performed to obtain the envelope signal a(m). The envelope amplitude of each eigenmode component IMF after decomposition is different, and in order to reduce the effect of the resulting error, it is normalized to obtain p_m, the normalized processing formula can be expressed as:

$$p_m = \frac{a(m)}{\sum_{m=1}^{M} a(m)} \tag{4}$$

In the above equation, $m = 1, 2, \cdots, M$. The envelope entropy value is obtained for the normalized envelope signal, and the formula can be expressed as:

$$E_P = -\sum_{m=1}^{M} p_m \lg p_m \tag{5}$$

The envelope entropy values of the local best components are compared at each iteration, and the smallest corresponding IMF components and the number of modal decompositions K are selected from them, and the penalty factor is the optimal solution of this search.

The overall flow of the variational modal decomposition algorithm optimized based on the sparrow search algorithm is shown in Figure 1.

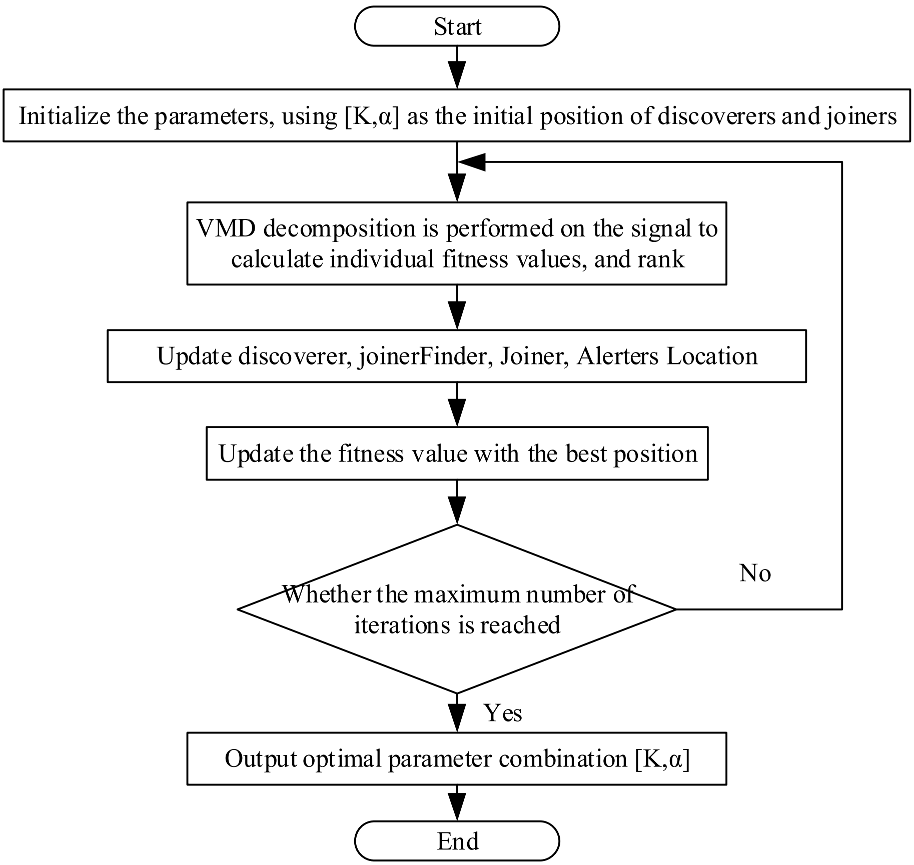


Figure 1. Overall flow of the SSA-VMD algorithm

In order to verify the superiority of the SSA-VMD algorithm in optimizing parameters, the PSO-VMD algorithm, GA-VMD algorithm and SSA-VMD algorithm are compared and experimented, and the iterative update comparison is shown in Figure 2.

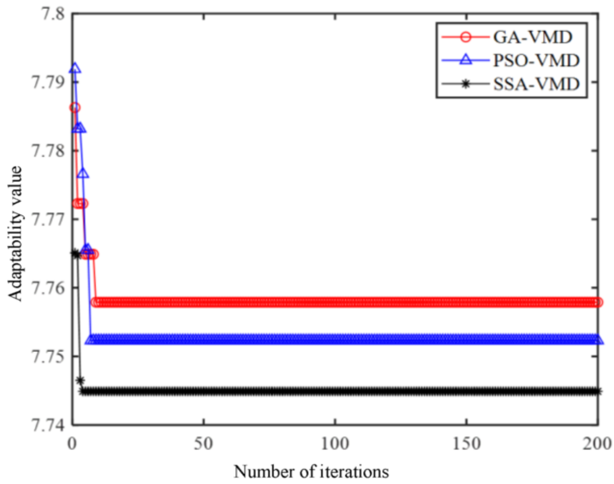


Figure 2. Comparison of decomposition algorithm iterative updates

According to Figure 2, Sparrow search algorithm based variable modal parameter optimization for pipe vibration signal decomposition with the fastest convergence rate. The minimum fitness value means that the decomposition of the pipe vibration signal is faster and more useful characteristic information is retained after the decomposition.

In summary, the decomposition performance of the SSA-VMD method is superior, so this paper uses SSA-VMD to decompose the pipe vibration signal.

2.2 Improved Support Vector Machine Based Pipeline Leak Identification Algorithm

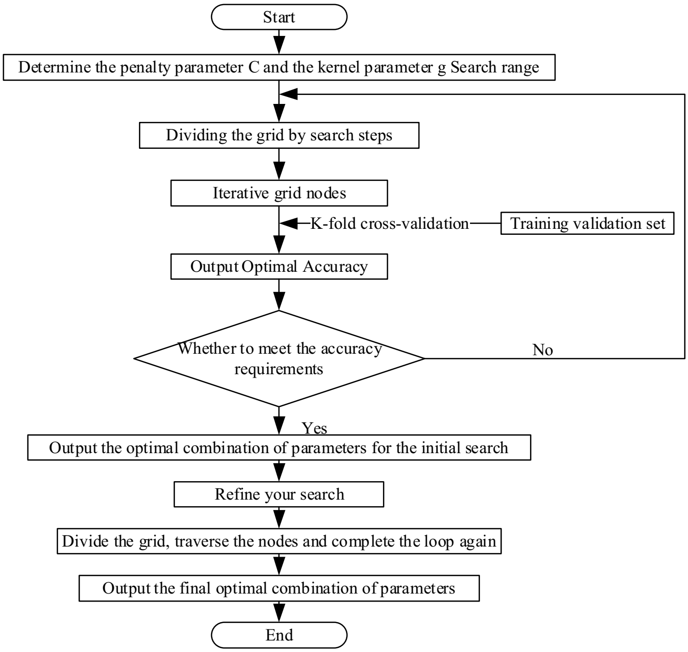


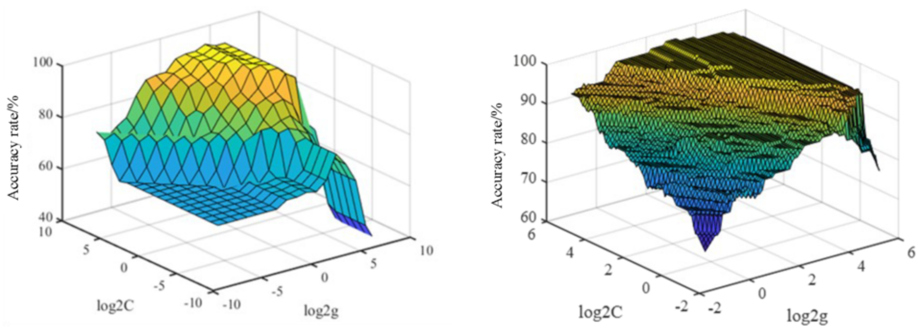
Figure 3. Improved grid search method process

The decomposed IMF components of the SSA-VMD algorithm are sorted according to the energy magnitude from largest to smallest, and the first four sorted IMF components are selected to extract features and construct feature vectors [13]. Support Vector Machine (SVM) algorithm is a pattern recognition algorithm proposed based on statistical learning theory and the principle of structural risk minimization[14]. Which has high generalization ability and is suitable for small sample learning. In this paper, the radial basis kernel function is used as the kernel function of the support vector machine, the parameters to be optimized are the penalty parameters and the parameters of the kernel function.

In this paper, we use an improved grid search method[15]to find the parameters of the support vector machine. The flow of the improved grid search method is shown in Figure 3.

3. Experimental Validation

In order to verify the effectiveness of the pipeline leakage diagnosis algorithm, vibration signal data were collected for five operating states of the pipeline, including normal pipeline, knocking pipeline, tributary water, round hole leakage, and narrow slit leakage. Decomposition of pipe vibration signals using SSA-VMD, identification of pipeline operating status.



(a) Preliminary grid search classification recognition accuracy

(b) Fine grid search class recognition accuracy

Figure 4. Search classification recognition accuracy

The preliminary grid search classification recognition accuracy is shown in Figure 4(a), and the preliminary grid search method obtained the optimal combination of parameters as [C =16, g =8]. After refining the grid search, the classification recognition accuracy is shown in Figure 4(b), the optimal combination of parameters is [C =$2^{3.4}$, g =$2^{2.7}$]. The optimal accuracy of four-fold cross-validation is 97.5% at this point.

The results of the classification and identification of pipeline operation status without optimization are shown in Figure 5. Its accuracy rate was 69.17%. The optimal parameters of the support vector machine after refinement search are input into the support vector machine model, and the classification recognition results are shown in Figure 6, its accuracy rate is 96.67%.

In conclusion, the experimental results show that the pipeline leakage diagnosis algorithm can effectively identify the pipeline operation status. The classification and identification accuracy based on the improved grid search method is significantly higher than that when default parameters are used.

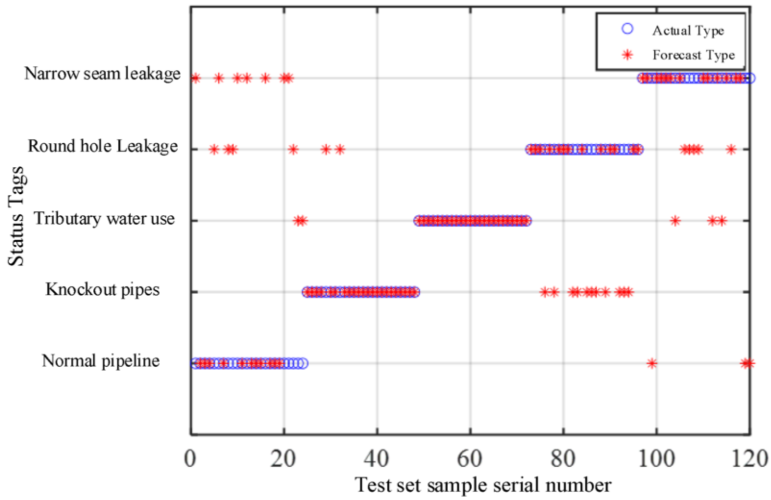


Figure 5. Classification recognition results without optimization

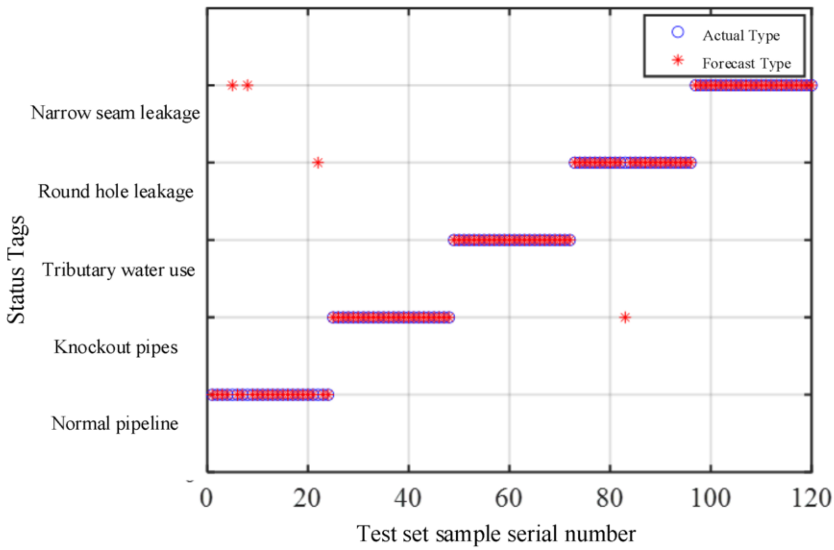


Figure 6. Classification and recognition results after optimizing parameters

4. Conclusion

In this paper, in order to solve the nonlinear and non-stationary problems of pipeline vibration signals, firstly, the vibration signals are decomposed by VMD; secondly, the variational modal decomposition algorithm is applied in combination with the sparrow search algorithm, and the parameters of the variational modal decomposition are optimized by using the SSA-VMD algorithm; again, the combined feature vectors are constructed for the decomposed vibration signals; finally, the support vector machine is optimized by using the improved grid search method. The experimental results show that the support vector machine optimized by the improved grid search method has a higher recognition accuracy.

References

[1] Abd Rahman N, Muhammad N S, Mohtar W H M W. Evolution of research on water leakage control strategies: where are we now[J]. Urban Water Journal, 2018, 15(7-8): 1-15.

[2] Kilic R. Effective Management of Leakage in Drinking Water Network[J]. Acta Physica Polonica, 2016, 130(1): 479-483.

[3] Barton N A, Farewell T S, Hallett S H, et al. Improving pipe failure predictions: Factors affecting pipe failure in drinking water networks[J]. Water Research, 2019, 164(1): 114926.1-114926.16.

[4] Pietrucha-Urbanik K, Tchórzewska-Cielak B, Eid M. Water Network-Failure Data Assessment[J]. Energies, 2020, 13(11): 1-14.

[5] Meng Yu. Analysis of the causes of water leakage in urban water supply network and corresponding measures[J]. Cleaning World, 2021, 37(09): 159-160.

[6] Yang J, Wen YM, Li P. Extraction and identification of pipeline leakage acoustic signal based on correlation analysis and approximate entropy [J]. Journal of Instrumentation, 2009, 30(2): 272-9.

[7] EL-ZAHAB S, ABDELKADER E M, ZAYED T. An accelerometer-based leak detection system [J]. Mechanical Systems and Signal Processing, 2018, 108(AUG): 276-91.

[8] ZAHAB S E, MOSLEH F, ZAYED T. An Accelerometer-Based Real-Time Monitoring and Leak Detection System for Pressurized Water Pipelines [J]. 257-68.

[9] Xia Chuanqiang. Research and application of water supply pipe leak detection and localization based on VMD and mutual spectrum analysis[D]. Chongqing University of Posts and Telecommunications, 2020.

[10] Wang Zhenwei. Research on fault diagnosis method based on variational modal decomposition[D]. Yanshan University, 2015.

[11] Li X.Y, Jin W.Y. Research on rolling bearing fault diagnosis based on improved sparrow algorithm optimized support vector machine[J]. Vibration and Shock, 2023, 42(06): 106-114.

[12] Qiao Weibiao, Fu Zonghua, Du Mingjun, Nan Wei, Liu Enbin. Seasonal peak load prediction of underground gas storage using a novel two-stage model combining improved complete ensemble empirical mode decomposition and long short-term memory with a sparrow search algorithm[J]. Energy, 2023, 274.

[13] Xia Chuanqiang. Research and application of water supply pipe leakage detection and localization based on VMD and mutual spectrum analysis [D]; Chongqing University of Posts and Telecommunications, 2020.

[14] CHERKASSKY V. The Nature Of Statistical Learning Theory [J]. IEEE Transactions on Neural Networks, 1997, 8(6): 1564.

[15] Liu S, Zhang ZB. Optimization of SVM parameters based on improved grid search method [J]. Journal of Jiangxi University of Technology, 2019, 40(01): 5-9.