Method of detecting pipeline leakage location based on multiresolution analysis

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Abstract: Aiming at the problem of low precision of traditional pipeline leakage detection method, a high-precision pipeline leakage detection method based on acoustic signal is proposed, which combines multiresolution analysis of wavelet transform and cross-correlation algorithm of signal processing. As for the large amount of background noise in the pipeline, it is necessary to filter the high-frequency noise by wavelet transform. In order to improve the accuracy of localization, the noise is checked at different scales and the noise is filtered at lower scales to retain more details of the acoustic signal leakage. Combined with cross-correlation function, the location of pipeline leakage location is repeatedly positioned to improve the accuracy of positioning.

1 Introduction

Pipeline exists in various fields of industrial production. In the process of pipeline use, due to weather and natural corrosion, many pipeline leakage problems exist, which not only increases the cost of industrial maintenance but also causes potential safety hazards. It is of great significance for the long-term interests and safety of industrial production to locate the leakage pipeline accurately [1].

1.1 Method for detecting pipeline leakage

Traditional pipeline detection methods, such as flow method or artificial detection, have the problems of labour-consuming and inaccurate positioning.

In some special pipelines, such as heating pipelines, buried in the ground all year round, some intuitive pipeline detection methods are no longer available. Using acoustic signals to locate pipeline leakage has become a new research direction [2]. When the pipeline leaks, the medium in the pipeline sprays out because of the pressure difference, and the friction between the pipelines produces vibration, forms sound waves, and propagates along the pipeline to both sides. Collecting the acoustic signal and analysing it, the specific information of pipeline leakage can be obtained. In the process of using pipeline, there is a lot of background noise. These useless signals and useful acoustic signals are mixed together, which is the main factor affecting pipeline leakage location.

1.2 Method of improving calculation accuracy

The background noise is mostly high-frequency signal, and the useful acoustic signal contains ultra-low-frequency signal as low as 20 HZ. It is feasible to filter the mixed signal with high-frequency and retain the low-frequency signal. Multiscale analysis of hybrid signals can extract different frequencies of acoustic signals according to demand. The scale is higher, the frequency is lower [3, 4]. However, with the increase of the scale, the more details of the signal will be lost. Using appropriate algorithm to reduce the loss of details of the signal can improve the location accuracy of pipeline leakage. After filtering the hybrid signals at different scales, the filtered signals are cross-correlated. Acoustic signals generated by the same leakage point propagate along the pipeline to both sides, and the two signals are similar. After proper signal processing, the two signals are cross-correlated and a peak value will be generated. The peak acquisition sequence corresponds to the time difference between the leakage sound signals arriving on both sides of the pipeline [5]. In different scales of multiresolution analysis, different acquisition points can be obtained by signal processing. Optimised calculation of these acquisition points can further improve the positioning accuracy.

2 Filtering algorithm based on multiresolution analysis

As of the complex installation environment of the pipeline, there is lots of high-frequency noise in the collected leakage signals. Only after filtering the noise signal, can we use them to detect the leakage position of the pipeline [6]. When the pipeline leaks, the pressure difference between inside and outside the pipeline produces infrasound signal and propagates along both sides of the pipeline. The infrasonic signal is as low as 20 HZ and concentrated in the low frequency [7]. To analyse the leakage signal, we need to filter out useless background noise and save useful leakage information. The decomposed signal in each frequency band can be obtained by wavelet multiresolution analysis. The higher the scale, the lower the resolution of the decomposed signal, and the lower the frequency band can be obtained. By checking whether the high-frequency signal satisfies the Gaussian distribution, the high-frequency part of the noise concentration can be filtered directly and the useful signal can be retained [8].

2.1 Decomposition algorithm for multiresolution analysis

In the theory of multiresolution analysis, suppose there is a closed space \( L^2(R) \). Its closed subspace sequence \( \{V_j\}_{j \in Z} \) satisfies that:

(i) \( \{V_j\} \) is a nested sequence, it means:

\[
\cdots \subseteq V_1 \subseteq V_0 \subseteq V_{-1} \subseteq \cdots
\]

(ii) The union of all \( V_j \) is dense in \( L^2(R) \), it means:

\[
\text{close}_{L^2(R)} \bigcup V_j = L^2(R);
\]

(iii) The intersection of all \( V_j \) is zero function;

(iv) \( f(t) \in V_{j+1} \iff f(2t) \in V_j, \forall j \in Z \);

(v) \( f(t) \in V_j \iff f(t - 2^k) \in V_j, \forall k \in Z \);

(vi) There is a function \( \psi(t) \) in \( L^2(R) \), which makes \( \{\varphi_{j,k}(t) \in Z \} \) a Riesz basis of \( V_0 \), it means there is a unique sequence \( C_j \) for any \( f(t) \in V_0 \) that makes:

\[
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As of the existence of noise and error, there may be some deviation from high frequency to low frequency. As the leakage signal is decomposed on scale \( n \), \( n+1 \)⋯ and filtered on the high-frequency signal to get the leakage signal \( s(t) \) until \( j=5 \):

\[
s(t) = f(t) - (d_1 + d_2 + \cdots + d_j), \quad 1 \leq j \leq 5, j \in N
\]

### 2.3 Cross-correlation localisation algorithm

Suppose there are two continuous signals \( f_1(t) \) and \( f_2(t) \). Their cross-correlation operations are as follows:

\[
R_{f_1f_2}(\tau) = \int_{-\infty}^{\infty} f_1(t) \times f_2(t + \tau) \, dt
\]

If there is correlation between the two signals \( f_1(t) \) and \( f_2(t) \), then \( R_{f_1f_2}(\tau) \) will be peak. The peak corresponds to the time value \( \tau \) which corresponds to the interval between the leakage signals and the two sides. When the leakage signal results in the cross-correlation operation cannot get the obvious peak value, and thus cannot get the time value \( \tau \) between the leakage signal and the pipeline. After the improved multiresolution analysis and filtering, the signal \( s(t) \), \( 1 \leq j \leq 5 \) at different scales is obtained. As there are two sets of data, two sets of signals \( g_1(t), g_2(t) \), \( 1 \leq j \leq 5 \) will be generated by multiresolution analysis at different scales. After taking cross-correlation operation of these two sets of signals, \( R_{g_1g_2}(\tau) \) is got:

\[
R_{g_1g_2}(\tau) = \int_{-\infty}^{\infty} g_1(t) \times h(t + \tau) \, dt, \quad 1 \leq j \leq 5
\]

Record the value \( \tau_n \), \( 1 \leq j \leq 5 \) when \( R_{g_1g_2}(\tau) \) produces a maximum value. After filtering, two sets of leakage signals \( g(t), h(t) \) are obtained. Cross-correlation operations are performed on them and the cross-correlation operation waveform is shown in the following figure (Fig. 2).

As of the objective existence of noise, even if high-precision filtering is used, there is a big deviation between the positioning results \( \tau_j \) obtained by cross-correlation algorithm. The average accuracy of the detection results can be improved by taking several useful signals for analysis. As the leakage signal is a low-frequency signal, \( f(t) \) is decomposed on scale \( n \), \( n+1 \)⋯ and filtered on the high-frequency signal to get the leakage signal \( s(t) \) until \( j=5 \):

\[
s(t) = f(t) - (d_1 + d_2 + \cdots + d_j), \quad 1 \leq j \leq 5, j \in N
\]
value of all the results of array $\tau_j$ can get a reasonable value $\tau$ of time difference.

$$\tau = \frac{\sum_{i=1}^{5} \tau_i}{j}, \quad 1 \leq j \leq 5, j \in N$$  \hspace{1cm} (9)

Suppose the sensors are placed on both sides of the pipe, and they are $X$ meters away, the value of time difference is $\tau_s$. The propagation speed of acoustic signal in pipe is $v \text{ m/s}$. By mathematical calculation, the location of the leakage point can be determined to be $((X - v\tau)/2) \text{ m}$ away from the acoustic sensor A.

3 Conclusion

The multiresolution analysis algorithm is used to get signals of different frequency bands at different scales. The signals satisfying the characteristics of white Gaussian noise are filtered through noise checking. Considering the defect that the higher the scale, the greater the distortion of the signal, the lower the load scale is chosen to filter out the high-frequency noise and retain more details of the leakage signal. After multiple cross-correlations at multiple scales, the leakage location is confirmed to be more accurate.

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5 References

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