Design of Pump Station Operation Condition Monitoring System Based on MATLAB Simulation

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Abstract. In this paper, through analysis of pump station operation status monitoring system, on the basis of applying wavelet packet analysis to signals processing, MATLAB was used to simulate the design of pump station operation status monitoring system. In the simulation link, through the wavelet packet decomposition and reconstruction of the collected original signal and fault signal of the pump station rotor, fault signal can be judged by comparing and analyzing the characteristic vector, power spectrum and energy spectrum of the wavelet packet node. Real-time monitoring of running status of pump station unit rotor was realized, and a simple human-computer interaction interface was designed using MATLAB/GUI (Graphical User Interface), which is simple and convenient to operate. In the human-computer interaction system, the user can observe some characteristic values and spectrum of the rotor signal of the pump station through the drop-down menu, so as to quickly find the fault signal and realize real-time monitoring.

1. Introduction
At present, advanced automatic monitoring system of pump station status has been a computer monitoring system integrating data acquisition function, data transmission function, control function, protection function and management function. Applications of computer monitoring technology not only improve the safe operation level and operation management level of equipment in pump stations, but also enable the unattended operation in pump stations to be realized, and can improve the operation efficiency of pump stations [1]. However, automatic monitoring system of pump stations is still developing, and applications of many technologies requires further theoretical analysis and experimental study.

In this paper, eddy current displacement sensor was used to collect signals, and MATLAB was used to analyse the vibration signal through wavelet packet analysis to extract the eigenvalues of vibration signals. By analysing characteristic values, it can be observed whether the monitored rotor system was working normally, so as to complete the design of MATLAB based pump stations operating status monitoring system, realizing real-time monitoring of the pump station unit rotor operating state, and using MATLAB / GUI to design a simple Human-computer interaction interface.

2. Structural Design of Monitoring System for Pump Station Running State
The structural diagram of operation status monitoring system of pump station is shown in figure 1, and its specific structure is shown in figure 2. It is mainly composed of dispatching center, pump station monitoring center, communication platform, pump station remote measurement and control terminal, measurement and camera equipment.
CAN (Controller Area Network) bus module completes the forwarding of communication data between the electronic control equipment under the operation state of pump station. Sensor module used eddy current displacement sensor to collect data of rotor operating status of pump station. This sensor can accurately determine the operation of the equipment and the cause of the system failure, timely implement measures such as protection and advance maintenance of machines. Liquid crystal display module is used to display current operation status of pump station. Alarm & emergency module is used to send out an alarm signal when the system detects that the operating index exceeds its safety threshold, and automatically adopt the corresponding emergency method when necessary [2].

![Figure 1. Monitoring system structure diagram.](image1)

![Figure 2. Specific structure block diagram.](image2)

3. Research on Key Technologies

This section illustrates the advantages of the wavelet packet analysis method to analyze vibration signals through the research and comparison of different signal analysis methods.

3.1. Wavelet Analysis

The traditional signal analysis is mostly based on Fourier transform and Gabor transform. They are a kind of global analysis, that is, all the signals are analysed in time domain or frequency domain, which cannot reflect the main properties of non-stationary signals, the real-time frequency characteristics. Wavelet transform is a local transform analysis in time domain and frequency domain. Through multi-scale refinement operations, local information in signals can be effectively obtained.

The following describes the realization process of wavelet analysis in signal processing.

Let \( \varphi(t) \in L^2(R) \) where \( L^2(R) \) represents square integrable real number space, and its Fourier transform be \( \hat{\varphi}(\omega) \). When \( \hat{\varphi}(\omega) \) meets the allowable condition,

\[
C_\varphi = \int_{\mathbb{R}} \left| \hat{\varphi}(\omega) \right|^2 \cdot |\omega|^{-1} d\omega < \infty
\]

where \( \varphi(t) \) is referred to as mother wavelet [3]. For a continuous wavelet, its sequence is

\[
\varphi_{a,b}(t) = \left|a\right|^{-\frac{3}{2}} \varphi\left(\frac{t-b}{a}\right), a,b \in \mathbb{R}; a \neq 0
\]

where \( a \) is stretching transformation parameter and \( b \) is translational transformation parameter.

For any function \( f(t) \in L^2(R) \), the continuous wavelet transform is

\[
W_f(a,b) = \int_{\mathbb{R}} f(t) \varphi_{a,b}(t) \, dt \geq \left|a\right|^{-\frac{3}{2}} \int_{\mathbb{R}} \frac{f(t-b)}{a} \, dt
\]

Its inverse transformation is
\[ W_f(t)C^{-1}_e \int_R a^{-2} W_f(a,b) \left[ (t-b) \cdot a^{-1} \right] da db \] (4)

Time-frequency window characteristics of wavelet transform and short-time Fourier transform are different. The window shape of wavelet analysis consists of two rectangles,

\[ [b-a\Delta \varphi, b+a\Delta \varphi] \times \left[ \pm \omega_0 - \Delta \hat{\varphi} \cdot a^{-1}, (\pm \omega_0 \pm \Delta \hat{\varphi}) \cdot a^{-1} \right] \] (5)

where, the window center is \((b, \pm \omega_0 \cdot a^{-1})\), the width of time window and the width of frequency window are \(a\Delta \varphi\) and \(\Delta \hat{\varphi} \cdot a^{-1}\), respectively. Among them, \(b\) affects the position of the window’s phase plane on time axis, while \(a\) affects the position of the window on frequency axis and the shape of the window [4]. In this way, wavelet transform can achieve the sampling of the signal in the time domain, and the sampling steps of different frequencies can be changed at will. When analyzing signals at high frequencies, the time resolution of wavelet transform is relatively high and the frequency resolution is relatively low; when analyzing signals at low frequencies, the time resolution of wavelet transform is relatively low and the frequency resolution is relatively high [5]. This is consistent with the characteristics that signals change rapidly at high frequencies and slowly changes at low frequencies. In a word, compared with short-time Fourier transform, wavelet transform has better time-frequency window characteristics [6-7].

Wavelet analysis has excellent flexibility and extended functions, and can decompose the signal into low frequency and high frequency, but wavelet analysis can only decompose the low frequency signal, and no longer decompose the high frequency signal [8].

### 3.2. Wavelet Packet Analysis

In operation status monitoring system of pump station, sometimes the signal in a specific time domain or frequency domain must be analyzed. In order to solve the defect that the wavelet transform cannot resolve high-frequency signals, this paper proposes wavelet packet analysis. Wavelet packet function is

\[ G_{j,k}^n = 2^j G^n(2^j t - k) \] (6)

The subscripts \(j\) and \(k\) in the formula represent index scale and transformation operation respectively. In general, the first two wavelet packet functions are regarded as scaling function and wavelet function respectively [9],

\[ G_{0,0}^0(t) = \begin{cases} x(t), & n=0 \\ y(t), & n=1 \end{cases} \] (7)

When \(n = 2, 3, 4, ..., N\), the corresponding wavelet packet function is given by following relationship.

\[ G_{j,0}^n(t) = 2^{j/2} \sum_k \left( \frac{(1)^n}{2} + \frac{(1)^{n+1}}{2} \right) g(k) G_{j,k}^{n+1}(2^j t - k) \] (8)

where \(g(k)\) and \(h(k)\) are a set of orthogonal mirror filter banks, which are related to the scale function and mother wavelet [10]. As long as the result of multiplying signals with special basic function is calculated, time domain signals can be analysed in detail [11]. The correlation between the function and wavelet packet can be calculated by following method,

\[ G_{j,n,k} \leq f, G_{j,k}^n \geq \int f(t) G_{j,k}^n(t) dt \] (9)

The following is wavelet packet decomposition and reconstruction.

Suppose \(g_j^i \in u_j^i\), then \(g_j^i\) can be expressed as

\[ g_j^i = \sum_d d_j^i \sum_{n} d_j^{i,n}(2^j t - 1) \] (10)
From above equation (10), wavelet decomposition is to decompose $g^j_{j+1}(t)$ into $g^j_2(t)$ and $g^j_2(t)
$. Wavelet packet decomposition algorithm is to find $\{d_{j,n}^1\}$ and $\{d_{j,n}^{1,2}\}$ by $\{d_{j,n}^1\}$, is

$$d_{j+1,m}^{1} \begin{cases} \sum_k h_{k-2} d_{j,n}^{m,n} , \quad m=2n \\ \sum_k g_{k-2} d_{j,n}^{m,n} , \quad m=2n+1 \end{cases}$$

(11)

The reconstruction algorithm of wavelet packet is to find $\{d_{j,n}^{1,2}\}$ by $\{d_{j,n}^{1,2}\}$ and $\{d_{j,n}^1\}$, is

$$d_{j}^{n} = \sum_k [h_{k-2} d_{j,n}^{k+1,2} + g_{k-2} d_{j,n}^{k+1,2n+1}]$$

(12)

Wavelet packet analysis is derived on the basis of wavelet analysis, and it makes up for the defect that wavelet analysis cannot decompose high-frequency signals. It can decompose multiple details and approximate narratives at the same time, while wavelet transform can only break down an approximate narrative [12]. In addition, wavelet packet transform can effectively analyse and process some unsteady signals [13-14]. Therefore, the signal processing methods involved in the monitoring system of pump station operating state designed in this paper mainly used wavelet packet analysis method.

4. Simulation of Pump Station Operating Condition Monitoring System

In this paper, the data collected by eddy current displacement sensor was used as the data source to analyze the rotor system. Wavelet packet was decomposed on signals, and then wavelet packet node was reconstructed. According to reconstructed wavelet packet nodes, the maximum singular value of each node matrix, namely the norm, was obtained, and the standard deviation of each node matrix was calculated, so as to constitute the characteristic vector of the signal [norm, standard deviation], and then the power spectrum and energy spectrum of signals were obtained [15], and signals were analyzed.

In order to accurately detect fault characteristic signals of the rotor system [16], the following analysis steps were adopted.

Step 1: Use db1 wavelet packet with depth of 3 to decompose original signals and fault signals; Step 2: Reconstruct the third layer node of wavelet packet;

Step 3: Calculate the norm and standard deviation of each node in the third layer, so as to obtain eigenvectors;

Step 4: Carry out Fourier transform on wavelet packet reconstruction coefficients of each node in order to obtain the power spectrum and energy ratio of each node on the third layer. Then compare the power and energy ratio of the same node to select the power and energy ratio to be the basis of fault characteristics.

It is difficult to find out whether signals are normal from figure 3, so it is impossible to accurately judge whether the rotor system is working properly just from time domain waveform.

It can be observed from figures 4a-4b that there are obvious differences between original signals and fault signals in wavelet packet nodes of [3,3], [3,7] and [3,8].

By comparing the power spectrum of each node from figures 5a-5b, it can find that there are mainly differences at [3,7] and [3,8], which are particularly obvious at [3,7]. Table 1 shows the eigenvectors of original signals and fault signals [norm, standard deviation].

| Table 1. Eigenvectors of normal signals and fault signals. |
|-----------------|-----------------|-----------------|-----------------|
| Signals Normal  | snorm1=23.8245,19.5523,5.9173,4.9607,4.2627,7.3377,3.2880,6.7892 | std1=0.5524,0.6186,0.1872,0.4733,0.1349,0.2322,0.1040,0.2148 |
| Signals Fault   | snorm2=20.8380,17.9318,11.0113,17.2410,4.0523,6.9193,7.6212,8.3144 | std2=0.4156,0.5673,0.3484,0.5455,0.1282,0.2189,0.2411,0.2631 |
Figure 3. Time-domain waveform of original signals and fault signals.

Figure 4. Original signals and fault signals were decomposed by db1 wavelet packet with depth of 3, and then the nodes in the third layer of wavelet packet were reconstructed.

Figure 5. Power spectrum of the third layer nodes of original signals and fault signals after wavelet packet decomposition and reconstruction of the depth 3 db1 wavelet packet.

In energy spectrum from figures 6a-6b, it is easier to observe the obvious difference between original signals and fault signals at [3,3] and [3,7].

This paper used GUI to design human-computer interaction interface, which is shown in figure 7, this method is simpler than the way through command window.

Figure 6. Energy ratio of original signals and fault signals through nodes of the third layer decomposed by the depth 3 db1 wavelet packet decomposition.

Figure 7. Interactive interface: when running this interface, the system selects the original signal by default. In the drop-down menu, signals to be watched can be selected, then click run to observe the selected graph.

5. Conclusion

In this paper, the operating status monitoring system of pump station was analyzed and signals acquisition and processing were studied. The fault monitoring system of the rotor system of pump station was developed by MATLAB simulation. The feasibility of the design was analyzed through simulation. In this paper, an advantageous wavelet packet analysis method was proposed for signals processing. Through simulation and GUI design of MATLAB simulation based on the pump station unit rotor status monitoring, easy to operate, to promote the pump station operation status monitoring system research is
of great significance. At the same time, it also has a certain degree of simplicity. The research in this field still needs more practical comparison and theoretical analysis and improvement. In the future, more consideration should be given to the applicability.

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