Processing of the Passive Drilling-bit Ranging Signal Based on Wavelet Packet

Quanzhi Yang¹a,Xiaobin Zhang²b,Xiaolong Yu³c,Xianlun Yang⁴d,Weifeng Li⁵e,Yunyi Hou⁶f

¹Research Institute of Shaanxi Yanchang Petroleum (Group) Co. Ltd. Xi’an, China
²Institute of Exploration and Development Petro China Changqing Oilfield Company Xi’an, China
³Research Institute of Shaanxi Yanchang Petroleum (Group) Co. Ltd. Xi’an, China
⁴Research Institute of Shaanxi Yanchang Petroleum (Group) Co. Ltd. Xi’an, China
⁵Research Institute of Shaanxi Yanchang Petroleum (Group) Co. Ltd. Xi’an, China
⁶Research Institute of Shaanxi Yanchang Petroleum (Group) Co. Ltd. Xi’an, China

a244211126@qq.com, b1007300745@qq.com, c595385177@qq.com, d108461284@qq.com, e281613901@qq.com, f75742803@qq.com

Abstract. Recent technological advances have increased interest to acoustic ranging especially the passive acoustic ranging which is easier to operate in the oilfield. For analyzing the non-stationary drilling-bit signal, the conventional discrete Fourier Transform (DFT) has been known to be less efficient. A new extraction method based on wavelet packet (WP) is presented. In the signal processing, WP is used to decompose the original drilling-bit signal into the sub-frequency bands (SFBs). By analyzing energy spectrum of the SFBs, the first four SFBs are found that contain the characteristic of the drilling-bit, and the specific frequency band of the drilling-bit signal is determined after power spectrum analyzing. The field test shows that when the bit is near to the casing of the adjacent well, the reconstruction drilling-bit signal changes significantly which can give warning accurately.

1. INTRODUCTION

With the development of the offshore (onshore) oil and gas exploration, extended reach horizontal well, sidetracking well and large cluster well become more and more popular, high-density infill wells project launched one after another, and avoiding well collisions has become an increasingly critical challenge for the drilling industry [1]. Once the wellbore collision occurs, it would result in huge economic loss and even serious environment pollution. The industry has an increasingly need for an effective way to reduce or eliminate well collision risk.

Well collision avoidance is the use of ranging technology to avoid other wells, where conventional survey techniques may not be adequate. The ranging technology can reduce the relative uncertainty of the offset wellbore position, which is especially advantageous when the combined positional uncertainty of the two wells exceeds an acceptable risk threshold [2]. There are two kinds of ranging technology, the Magnetic ranging and the Acoustic ranging. Magnetic ranging technologies are based on the measurements of magnetic field disturbances attributed to the steel in the offset wellbore casing or
By interpreting down-hole magnetic field distortions, the relative distance and direction of the offset wellbore, which is the source of the magnetic disturbance, can be determined. Like magnetic ranging methods, an acoustic signal can be used to locate the target wellbore, or to complement the current technique which relies on magnetic properties. By knowing the time required for the sound to travel in the formation and which direction the sound is coming from, the ranging distance and direction can be determined. Recent technological advances have increased interest to acoustic ranging especially the passive acoustic ranging which is easier to operate in the oilfield [3, 4].

The common passive acoustic source is the noise that is generated by the drilling bit. Because the drill bit vibration signal is non-linear and non-stationary, conventional discrete Fourier Transform (DFT) based on the assumption that the signal is stationary and linear can result in false information. How to extract characteristic form the collected data is a tough problem. Considering the actual situation of the drilling site, in this paper we take the Wavelet Packet method to extract useful information, and focus on the local characteristics of the signal to improve the interpretation accuracy.

2. PASSIVE DRILLING-BIT RANGING MONITORING SYSTE

The basic components of the Passive Drilling-bit Ranging Monitoring system (Figure 1) consists of signal perceiving part (high sensitivity and low frequency acceleration sensors), signal filtration and amplification equipment, signal collection and analysis part. When the drill bit approaches an existing well, the drilling bit in rock-breaking operation generates strong vibration and higher frequency acoustic noise which can penetrates the well structure, and propagate over long distances within the well. Because the casing is an efficient propagation channel between the bottom and surface due to its low attenuation feature. Acceleration sensors installed at the top of the casing collect the vibration signal. The data is processed in real time and plotted versus measured depth of the well being drilled. By signal characteristic extraction we can estimate the extent the drill bit approaching the casing and forecasts the risk of collision based on signal changes.

![Figure 1: The Passive Drilling-bit Ranging Monitoring system](image)

3. SIGNAL PROCESSING BASED ON WP

Wavelet packet analysis is a time-frequency signal analysis method, which is a more sophisticated processing method than wavelet analysis, and is especially suitable for non-stationary signal analysis [5,6]. This method decomposes the signal into two parts, the low frequency and the high frequency step by step. Through the decomposition of n-layer wavelet packet, the signal can be decomposed into $j=2^n$ sub-frequency bands (SFBs). The reconstructed original signal can also be composed of these sub-bands which have the equal width.
If a signal frequency band is \([0, W]\), according to the principle of wavelet packet decomposition, the bandwidth of each sub-frequency is \(W/2^n\). Through wavelet packet decomposition, the energy distribution of each frequency component of the drill bit vibration signal and the location of the main frequency band can be analyzed. The schematic diagram of wavelet packet decomposition level is shown in Figure 2, where \(S\) represents the original signal, the beginning of \(V\) represents the low-frequency component, the beginning of \(W\) represents the high-frequency component, and the number represents the number of layers of wavelet packet decomposition \([7, 8]\). Because the wavelet packet has the ability to accurately describe high-frequency signals, it can more precisely describe the local information of the signal in different frequency bands.

![Figure 2 Sketch map of wavelet packet transform](image)

Like the Fourier spectrum analysis technique, the wavelet packet frequency band analysis technique is also based on the Parseval energy integral equation. The energy of the signal \(x(t)\) in the time domain is

\[
\|x(t)\|^2 = \int_{-\infty}^{\infty} x(t)^2 dt
\]

Equation (1) and the wavelet packet transform coefficients of \(x(t)\) are related by the Parseval energy integral equation, we can get

\[
\int_{-\infty}^{\infty} |x(t)|^2 dt = \int |C_{jm}|^2
\]

It can be seen from equation (2) that the wavelet packet transform coefficient has an energy dimension and can be used for signal frequency band energy analysis. The energy distribution of the signal in different frequency bands is caused by the different information contained in the signal. After wavelet packet decomposition, the distribution of the information components in the signal in each decomposition scale component is also different. There are also differences in the characteristic spectrum or energy spectrum coefficients in the frequency band, so the normalized energy in each SFBs of wavelet packet decomposition is considered as the signal feature. The signal processing flow is as shown in Figure 3.
4. FIELD TEST DATA ANALYSIS

The field test was performed on the platform ZCZ5267 (well number begins with ZCZ5267) using the Passive Drilling-bit Ranging Monitoring system (figure 4). The platform ZCZ5267 is located in the ZiChang coal mine in Ordos Basin (figure 5), and already drilled 8 directional well. In order to utilize the existing well sites, another 7 horizontal well are designed as a high-density infill wells project which has high well collision risk.

Figure.4 Sensors installation

Figure.5 Platform ZCZ5267

At the beginning of the experiment, the well 5267-1, 5267-2, 5267-3, 5267-4, 5267-5, 5267-6, 5267-7 and 5267-8 on the platform have stopped production, and well 5267P1, 5267P2, 5267P3, 5267P4 have been completion, Well 5267P5 was going to spud. Use software Compass to do the anti-collision scan
and select the well 5267P3, 5267P4 and 5267-6 as risk well to monitor while drilling well 5267P5. The sampling frequency is 4000Hz, and playback data shown in Figure 6 (selected part when 5267P5 is approaching well 5267P3). The amplitude of the signal of well 5267P3 (the second channel) changes significantly, and have clear relation with the signal of well 5267P5 (the first channel).

![Figure 6](image)

Figure 6  Signal in time domain when well 5267P5 approaching well 5267P3 (well depth 350m)

According to signal processing flow, do the signal feature extraction of the first and fourth channel signal in Figure 3. First make Wavelet Packet decomposition, use the DB4 wavelet packet to do 3 layers Wavelet packet decomposition and get SFBs, and then do the normalized energy distribution (Figure 7).

![Figure 7](image)

Figure 7  Wavelet packet energy spectrums of bit signal

In Figure 7, the energy of SFB1-4 hold majority of the original signal energy, over 90%, and indicates that the impact characteristics of drill bit concentrated in the first few SFBs, especially in SFB1, SFB2, SFB4. As SFB3 and SFB 5-8, the five components change slowly in time domain, have the low amplitude and energy, generally do not contain the impact characteristic of the drill bit. Take the first four SFBs to do the power spectrum analysis (Figure 8).
In Figure 8, the power spectrum shows that the drilling bit signal has large frequency distribution, the main frequency is from 0 Hz to 1000Hz, and the signal energy of 200 Hz to 300Hz is the highest, which frequency reflects the impact between drill bit and formation. The reconstruction signal in this frequency band can be used to filter the interference noise and get the characteristic information. After processing a large number of measured data, the results of the SFBs and power spectral analysis are the same. We select the SFB1 and SFB2 of the drilling well signal and the risk well signal to reconstruct, and take their energy as a measure of the drilling bit approaching the adjacent well distance, the results of Field Test Data Analysis for collision prevention in cluster wells are shown in Table 1 and Figure 9.

Table 1 and Figure 9 show the variation of relative energy with center distance when well 5267P5 approaches well 5267P3. It can be seen that the relative energy of the time-domain signal has a clear increasing trend with the approach of the drill bit to the dangerous adjacent wellbore. With the increase of the center distance, the signal energy decays exponentially. According to the result of analysis, the relative energy of the signal can be used to predict the bit's distance to the adjacent casing.

| well depth/m | C-C distance/m | relative energy | well depth/m | C-C distance/m | relative energy |
|--------------|----------------|----------------|--------------|----------------|----------------|
| 150.00       | 5.42           | 0.5339         | 290.00       | 4.07           | 0.8412         |
| 160.00       | 5.32           | 0.5602         | 300.00       | 4.05           | 0.8623         |
| Center Distance (m) | Relative Energy | Frequency Distribution | 200-300Hz Frequency Band |
|--------------------|-----------------|------------------------|--------------------------|
| 170.00             | 5.21            | 0.5905                 | 4.14, 0.8261             |
| 180.00             | 5.09            | 0.6256                 | 3.20, 0.8261             |
| 190.00             | 4.97            | 0.6626                 | 3.30, 0.7690             |
| 200.00             | 4.85            | 0.7019                 | 3.40, 0.7226             |
| 210.00             | 4.73            | 0.7436                 | 3.50, 0.4850             |
| 220.00             | 4.67            | 0.7653                 | 3.60, 0.3585             |
| 230.00             | 4.70            | 0.7543                 | 3.70, 0.3489             |
| 240.00             | 4.72            | 0.7471                 | 3.80, 0.1631             |
| 250.00             | 4.67            | 0.7653                 | 3.90, 0.0712             |
| 260.00             | 4.53            | 0.8185                 | 4.00, 0.0501             |
| 270.00             | 4.36            | 0.8261                 | 4.10, 0.0341             |
| 280.00             | 4.19            | 0.8354                 | 4.20, 0.0263             |

Figure 9: Relative energy changing with the center distance as well 5267P5 approaches well 5267P3

5. CONCLUSIONS
The characteristic extraction method based on Wavelet Packet was proposed to process the drill bit vibration signal for wellbore anti-collision monitoring, and proved effective by the field test data analysis. The power spectrum analysis shows that the drill bit vibration signal has large frequency distribution, and 200-300Hz frequency band particularly reflects the impact function between the bit and formation. Reconstruct signal in 200-300 Hz frequency changes significantly when the bit is approaching the existing well casing and can give warning accurately.

ACKNOWLEDGMENTS
This work was financially supported by National Science and Technology Major Project of China (2017ZX05039-003-010).

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