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Research on mud pulse signal detection based on adaptive stochastic resonance

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ABSTRACT

The original data signals have small amplitude with a long distance signal transmission from the underground to the ground. And thousands of meters of drilling mud channel in the drilling process will contain a lot of noise sources. Therefore, the original mud pulse signals are submerged by the complex noise environment. Detecting the original signal after receiving the signal on the ground is still a serious issue. In connection with mud pulse signal detection under complex background in measurement while drilling (MWD), nonlinear bistable stochastic resonance theory and the production condition was analyzed. On the basis of this, a method of using genetic simulated annealing algorithm to adaptive optimize the parameters of stochastic resonance was proposed to realize the detection of mud pulse signal in the background of complex noise. Finally, through the simulation experiment and the field verification, this method realizes the signal detection even under the low signal-to-noise ratio (SNR). And the proposed method can overcome the shortcomings of existing detection method of signal detection performance in low SNR. It proves the proposed method's effectiveness and feasibility.

1. Introduction

Original mud pulse signals are the transmission carrier of logging data in measurement while drilling (MWD). In complex noise environment, the signals are difficult to detected with the transmission is affected by many factors, such as drilling mud pumps, stalling of mud motor, stick/slip phenomena,etc. Therefore, detection technology has been still a hot spot and difficult problem (Liu and Su, 2000; Zhao et al., 2007).

In recent years, the researchers mainly focus on how to improve the signal transmission rate and detect the received data on the ground to improve the signal to noise ratio. Current wireless MWD system has a high requirement of rate of signal transmission, Li et al. (2016) proposed a new datagram protocol to avoid redundant data transmission by incremental transmission technology and shortens the length of the datagram (Li et al., 2011). This is also the most direct way to improve the transmission rate of mud pulse signal. Zhu et al. (2013) proposed an efficient numerical model matching method to simulate and analyze the coupling structure of the drill pipe, and preferred to rectangular transmission line inside of the drill pipe in order to get better transmission performances. In addition, researchers are also constantly improving the signal transmission medium. Li et al. (2016) proposed to use guidance of metal pipes and relay of transceivers to realize wireless mud pulse signal transmission.

Unfortunately, the continuous wave signal is relatively weak, and the noise interference is relatively serious. It is a difficult problem for the application of MWD system to restore the original signal transmitted from the ground. Tu et al. (2011) used Cross-correlation detection to eliminate the noise of mud pulse signal, and this method has anti-interference ability. Zheng et al. (2012) used empirical mode decomposition (EMD) method to construct different low-pass filters for intrinsic mode components and then shapes square waves.

The established degree of approximation reaches 0.7719 and the degree of association is as high as 0.8929. Wavelet transform has been used for mud pulse signal detection and isolates the original signal from complex noise (Ni et al., 2010; Chen et al., 2010). Zhang et al. (2008) used wavelet neural network principle to detect weak mud pulse signal buried under complex noise environment. Mohammed et al. (2013) used continuous Morlet wavelet transform to detect mud pulse signal. Qiao et al. (2016) proposed an adaptive filtering algorithm which combines both the adaptive noise canceller and the adaptive notch filter. The proposed method can effectively filter pump impulse noise and protect useful signal energy. Xu and Yang (2014) suggested that the frequency range of the original signal is firstly determined by the piecewise average periodogram and then the mud signal is detected by Hamming digital filter. Shao et al. (2017) used differential signal extraction method to detect mud pulse signal from noise.

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Nomenclature

a	structural parameters of nonlinear bistable systems
b	structural parameters of nonlinear bistable systems
A	signal amplitude
D	noise density
R	Kramers rate
SNR_{out}	SNR of output signal, dB
T	current temperature, $°C$
P_{size}	population size
P_S	signal power, dB
P_N	noise power, dB
$f(\cdot)$	fitness value of population
f_0	frequency of original signal, Hz
f_s	sampling frequency of signal, Hz
T_i	initial temperature, $°C$
T_f	final temperature, $°C$
R	coefficient of temperature drop
SNR_{in}	SNR of output signal, dB

At present, the commonly used mud pulse signal detection methods, such as digital filter method, wavelet denoising method, EMD method, etc., can only detect higher SNR input signal, and the minimum SNR is usually greater than −20 dB. These methods cannot meet the actual engineering needs. Stochastic resonance (SR) has been applied in fault detection, vibration measurement and other signal processing fields since proposed by Benzi et al. (1981). It can detect weak signals in complex noise background. But no one has ever used stochastic resonance technology to detect mud pulse signal before.

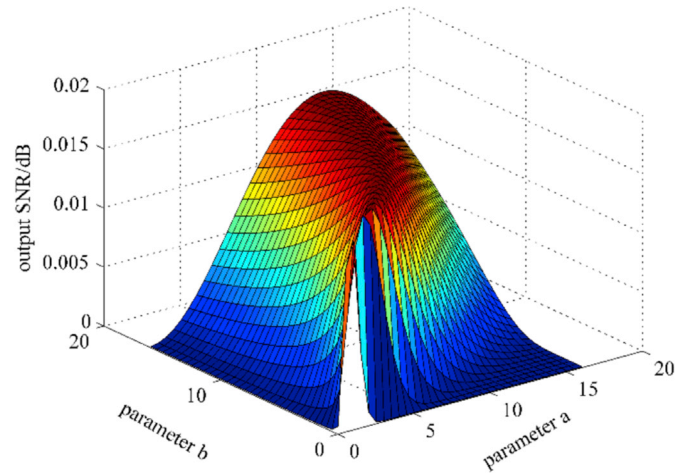

Fig. 2. Graph of the best fitness value changes with the parameter value.

Based on the research results of existing nonlinear bistable stochastic resonance, stochastic resonance system parameters are selected adaptively by using genetic simulated annealing algorithm, and the optimized system is used to detect mud pulse signal under complex noise background. Research shows that the optimum parameters of stochastic resonance obtained by the algorithm can effectively detect the mud pulse signal at lower SNR of input signal. And it can improve the SNR of the output signal.

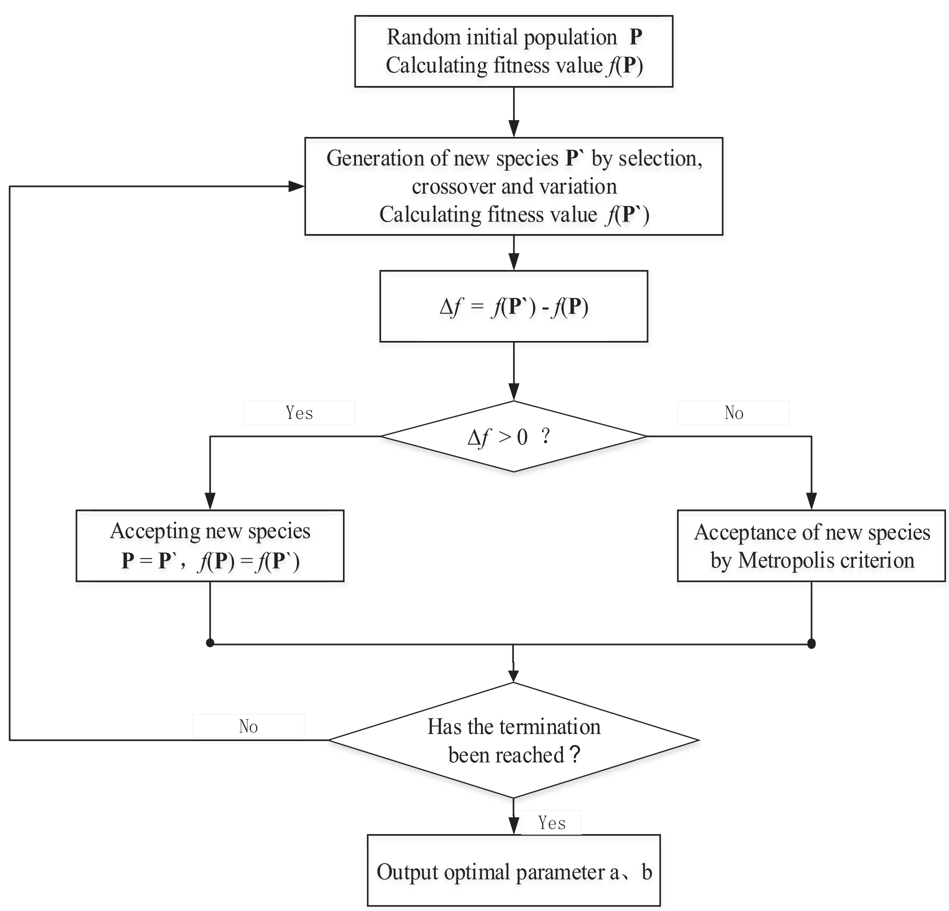

Fig. 1. Flow chart of genetic simulated annealing algorithm.