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# Effects of Barrier Parameter to Stochastic Resonance Signal-to-noise Ratio in Feature Extraction

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***Abstract***

*Effects of barrier parameter a to output signal-to-noise ratio (SNR) of bistable stochastic resonance in feature extraction was investigated in this paper. Barrier parameter a was changed with other systematic parameters fixed. The relationship between parameter a and the output SNR of non-linear stochastic resonance system was studied. This research provided us a novel way to extract the features using the non-linear stochastic resonance. The proposed technique is promising in the field applications for the human real-time status monitoring.*

***Keywords:*** *barrier parameter, stochastic resonance, signal-to-noise ratio, feature extraction, non-linear*



## 1. Introduction

Stochastic resonance has been utilized in many research fields, such as mechanical system analysis, signal processing, bioinformatics, etc [1-5]. This theory hires external noise to induce a synchronous resonance within a non-linear bistable system. At this time, an evident improvement in signal-to-noise ratio has been obtained so that some important features can be extracted under this best state. In this paper, a non-linear bistable stochastic resonance system is used to extract the sports features provided by a bluetooth stack-based wireless sensor network. The system output SNR was presented instantaneously with the barrier parameter a changes from 0 to 8. Output SNR analysis results indicate that the SNR changes with the change of barrier parameter a.

## 2. Experimental

Stochastic resonance has three fundamental elements: a non-linear system, a weak coherent input signal, and an additional doze external noise source. The non-linear bistable system can be described as the motion of an overdamped Brownian particle in a bistable potential in the presence of periodic forcing:

$$\frac{dx}{dt} = -\frac{dV(x)}{dx} + MI(t) + C\xi(t) \tag{1}$$

Where $x$ is the position of the Brownian particle, $t$ is the time, M and C are adjustable parameters, $I(t) = S(t) + N(t)$ denotes an input signal $S(t)$ and intrinsic noise $N(t)$, $\xi(t)$ is the external noise, and $V(x)$ is the simplest double-well potential with the constants $a$ and $b$ characterizing the system.

$$V(x) = -\frac{1}{2}ax^2 + \frac{1}{4}bx^4 \tag{2}$$

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Equation (1) can be written as:

$$\frac{dx}{dt} = ax - bx^3 + MI(t) + C\xi(t) \tag{3}$$

The minima of $V(x)$ are located at $\pm x_m$, where $x_m = (a/b)^{1/2}$. A potential barrier separates the minima with the height given by $\Delta U = \frac{a^2}{4b}$. The barrier top is located at $x_b = 0$. When three elements of SR interact coherently, the potential barrier can be reduced and the Brownian particle may surmount the energy barrier and enter another potential well [30,33]. The intensity of signals will increase, which makes it possible that the weak signal can be detected from noise background.

Suppose the input signal is $I(t) = A\sin(2\pi ft + \varphi)$, where $A$ is signal intensity, $f$ is signal frequency. $D$ is external noise intensity. The most common quantifiers for stochastic resonance are the spectral amplification $\eta$ and the systematic output SNR. Here SNR method was adopted to character the system output, which has the following definition:

$$SNR = 2[\lim_{\Delta\omega \to 0} \int_{\Omega-\Delta\omega}^{\Omega+\Delta\omega} S(\omega)d\omega] / S_N(\Omega) \tag{4}$$

$S_N(\Omega)$ is the noise intensity in signal frequency range, and $S(\omega)$ is the signal power spectral density.

The hardware system consists of a wearable activity recording design using MMA7261QT series accelerometer sensors, a heart-rate measuring sensor utilizing a commercial Bluetooth module, and a PC with friendly controlling software. Three main modules are used when the wearable devices were to be adhered to volunteer body. Four volunteers (numbered by A, B, C, and D) are chosen from the university students to carry out experiments. The wearable devices are fixed on the volunteers' bodies, each volunteer sits on the chair for 15 minutes then experiments start. Activity varieties include: standing, walking, running, and football playing. The accelerometers only give us the reference parameters here. To digitize the recorded QRS wave, the ECG signal is sampled at 512 Hz. Heart rate signal is divided into continuous 1-minute segment of 8-seconds step. Instant heart rate (*H*(*t*)), the 1-minute increase ($\Delta HR_{1\ minute}$), and mean heart rate ($\overline{H_N}(t)$), defined as (5)~(7):

$$H(t) = \frac{60 \times f_s \times n}{\Delta t}. \tag{5}$$

$$\overline{H_N}(t) = \frac{1}{2N}\sum_{k=-N}^{N-1} H(t + \frac{50k}{f_s}). \tag{6}$$

$$\Delta HR_{T\ minute}(t) = H(t+T) - H(t). \tag{7}$$

Where n = 3, *N* = 300.

Noise intensity is just a parameter of SR model. SR model is used as a data processing method in this research. We use $I(t) = A\sin(2\pi ft + \varphi) + W(t) + N(t)$ as input matrix. It has a sinusoid signal $A\sin(2\pi ft + \varphi)$, accelerometer sensor response data $W(t)$, and intrinsic noise $N(t)$. Noise intensity changes within the range [0,900]. SNR between the output and input is calculated. A graphical illustration of SR processing is shown in Figure 1.

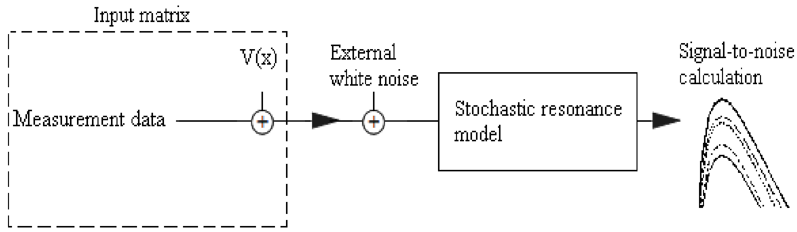


Figure 1. Graphical Illustration of Data Analysis Method

## 3. Results and Discussion

In the past twenty years, stochastic resonance has been used as engineering data processing method in numbers of research fields Bistable stochastic resonance theory has been widely investigated by researchers from many countries [6-12]. In this paper, experiments are held to explore the relationship between barrier parameter *a* and stochastic resonance when input signal intensity A is fixed. Action measurements of four volunteers are transmitted to PC for further analysis through Bluetooth devices. The experimental data of volunteer B is chosen and the systematic barrier parameter *a* varies from 0 to 8. Analysis results are displayed in Figure 2 to Figure 7. When parameter *a* put up at a low level (no more than 3.2), no obvious eigen peak appears. With the value varies from 4.8 to 8.0, the output SNR curve presents feature peaks gradually and we can see that four activities of the selected volunteer can be discriminated from each other. The optimized systematic barrier value is about $f_0$=8.0. Football playing owns the highest SNR peak value than the other activities, and standing owns the lowest. Accordingly, football playing leads to fastest heart rate and standing presents the lowest. With the increase of barrier parameter *a*, BSR peaks located noise intensities increase. The systematic barrier parameter *a* determines the position of SNR peaks. Based on this conclusion, we can use this characteristic to analyze heart rate features.

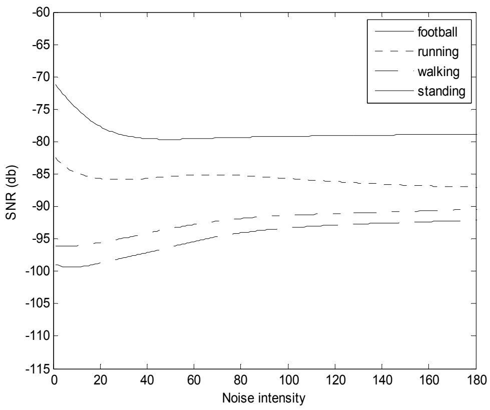


Figure 2. Output SNR Curves Related with Systematic Barrier Parameter *a*=0

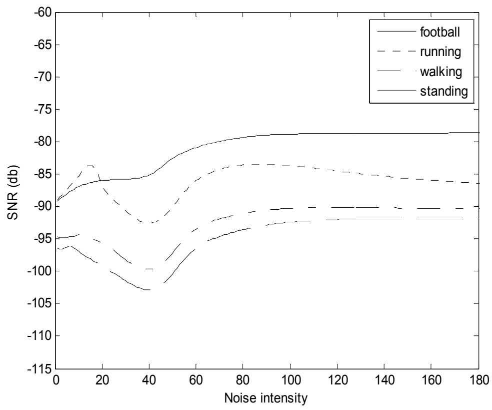


Figure 3. Output SNR Curves Related with Systematic Barrier Parameter *a*=1.6

Generally speaking, stochastic resonance occurs in non-linear systems, when a small periodic (sinusoidal) force is applied together with a large wide band stochastic force (noise). The system response is driven by the combination of the two forces that compete/cooperate to make the system switch between the two stable states. The degree of order is related to the amount of periodic function that it shows in the system response. When the periodic force is chosen small enough in order to not make the system response switch, the presence of a non-negligible noise is required for it to happen. When the noise is small very few switches occur, mainly at random with no significant periodicity in the system response. When the noise is very strong a large number of switches occur for each period of the sinusoid and the system response does not show remarkable periodicity. Between these two conditions, there exists an optimal value of the noise that cooperatively concurs with the periodic forcing in order to make almost exactly one switch per period (a maximum in the signal-to-noise ratio). In this study, stochastic resonance is used to extract the feature information of human body status. The proposed technique is promising in the field applications for the human real-time status monitoring. We have arranged a long-term plan to investigate the usage of this method in human body monitoring.

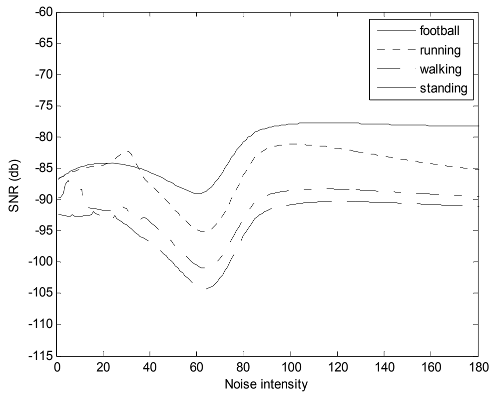


Figure 4. Output SNR Curves Related with Systematic Barrier Parameter *a*=3.2

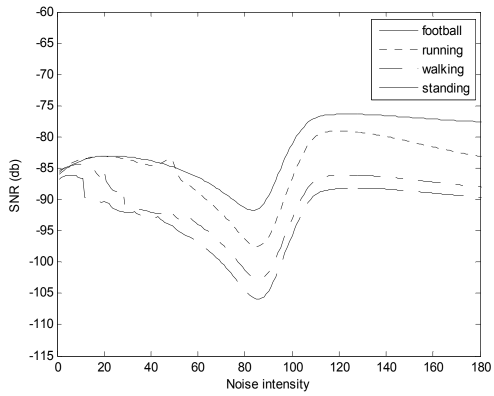


Figure 5. Output SNR Curves Related with Systematic Barrier Parameter *a*=4.8

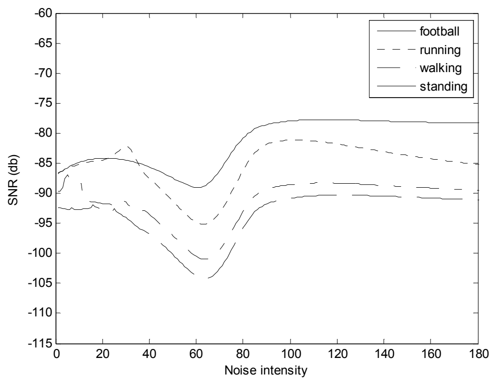


Figure 6. Output SNR Curves Related with Systematic Barrier Parameter *a*=6.4

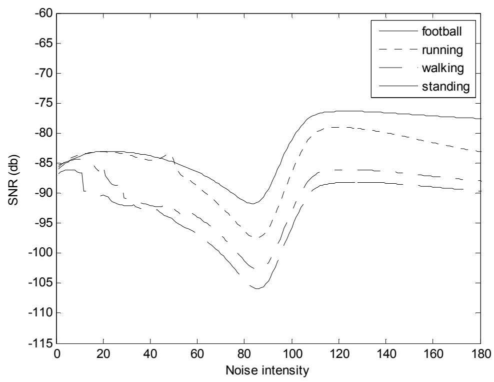


Figure 7. Output SNR Curves Related with Systematic Barrier Parameter *a*=8.0

## 4. Conclusion

The effects of systematic barrier *a* to BSR are investigated in this paper based on WSN signal measurement devices. With a variable systematic barrier parameter *a* range from 0 to 8.0, BSR non-linear system output SNR curves are calculated for further analysis. With an increase of parameter *a*, BSR peaks located noise intensities increase gradually. Thus, we could conclude that systematic barrier parameter *a* determines the scattering instance of SNR peaks. This method is promising in human bioinformatics analysis. In this study, stochastic resonance is used to extract the feature information of human body status. The proposed technique is promising in the field applications for the human real-time status monitoring.

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