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Stochastic resonance for a forest growth system subjected to non-Gaussian noises and a multiplicative periodic signal

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ABSTRACT

In this paper, the stochastic resonance (SR) phenomenon induced by a multiplicative periodic signal in a forest growth system which is excited by additive Gaussian noise, multiplicative non-Gaussian noise and noise correlation time is investigated. According to the fast descent method, the unified colored noise approximation and the SR theory, the analytical expression of the signal-to-noise ratio (SNR) is derived in the adiabatic limit. Via numerical calculations, each effect of the addictive noise intensity, the multiplicative noise intensity and the departure parameter from the Gaussian noise upon the signal-to-noise ratio (SNR) is discussed. It is shown that the addictive noise intensity always plays a significant role in stimulating the SR phenomenon. Conversely, the multiplicative noise intensity generally plays a remarkable role in restraining the effect of SR in most cases except for the case of $M = 0.01$. Moreover, the noise correlation time can also excite the SR effect. On the other hand, the departure parameter from the Gaussian noise and the forest growth rate can produce entirely different effects on the SNR under the different conditions of the system parameters.

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1. Introduction

It is well known that noise has been thought of as a source of disturbance in the signal processing performance. However, in the real world noise may play a positive and favorable role in enhancing the signal-to-noise ratio (SNR). The example which is most widely studied is stochastic resonance (SR). SR is a remarkable nonlinear cooperative phenomenon which has drawn increasing interest from physicists. Although there is no well accepted definition of SR, it can be viewed as an increase of the signal-to-noise ratio (SNR) at the output through an increase of the noise level at the input of the nonlinear system. Here, additive noise cooperates with the excitations. The main signature of SR is that the output SNR at the frequency of the sine wave excitation shows a maximum for an optimum amount of additive noise. The SR phenomenon occurs in nonlinear systems which possess a potential barrier and for which two characteristic times exist.

In fact, noise tuning, parameter tuning or array SR may not be suitable for a collected signal with noise whose intensity exceeds the resonance level, which is very common in the practical application of digital signal processing and weak signal detection [1–4]. Only in the case where the input noise arrives at the resonance region, could the system response follow

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the input signal so that the output SNR is enhanced in a nonlinear system [5–14]. When a weak signal and an additive white noise coexist, the maximum output signal-to-noise ratio and added noise can be determined by using the Fisher information [15–17]. There are at least three issues that may be of concern for signal processing or a detection procedure based on SR. The first issue is that the input noise cannot be reduced, only added to [11]. As a result, noise tuning SR is useless for a signal already submerged in a large noise floor. Relatively, parameter tuning SR is suitable for a variety of noise intensities to a certain extent. Then, the second issue is how a higher output SNR can be obtained for a nonlinear system induced by large noise intensity with the system parameters fixed. Finally, one cannot improve the output signal notably by adding system noise into each element of a SR array when the array input noise intensity has already exceeded the resonant amplitude.

On the other hand, the stochastic resonance phenomenon and dynamical behavior in biological and medicine fields have also drawn more and more interest from physicists and biologists [18–23]. Zeng et al. have studied the delay-induced state transition and stochastic resonance in a periodically driven tumor model with immune surveillance [24]. In the meantime, they have also investigated noise and delay-induced regime shift and stochastic resonance in an ecological system of vegetation [25,26]. Xu et al. have explored fluctuation induced extinction and the stochastic resonance effect in a tumor cell growth model with a periodic treatment [27]. Wang and Liu have discussed stochastic resonance for a metapopulation system driven by associated colored noises [28]. Wu and Zhu have studied the stochastic resonance in a bistable system with time-delayed feedback induced by non-Gaussian noises. [29] Wio et al. have also investigated the SR phenomenon and experimental evidence in a bistable and excitable system, gated traps and a general two-state system driven by non-Gaussian noises. [30–36] Duarte et al. have discussed the stochastic resonance of a periodically driven neuron under non-Gaussian noises [37]. Bag and Hu have studied the influence of noise on the synchronization of the stochastic Kuramoto model [38]. Hung and Hu have also investigated the constructive role of noise in a regulatory network [39]. Silchenko and Hu have discussed the multifractal characterization of stochastic resonance [40]. Recently, the SR phenomenon in monostable and bistable systems driven by multiplicative and additive noises have been studied in Refs. [41,42]. On the other hand, stochastic resonance in a linear oscillator system subjected to different noises was also investigated [43,44].

In this study, we aim to investigate the SR phenomenon of a stochastic forest growth system driven by the excitations of a multiplicative non-Gaussian noise, an additive Gaussian noise and a multiplicative periodic signal. In light of the fast descent method, the unified colored noise approximation and the SR theory, it is found that all kinds of SR phenomena appear with the variation of the noise correlation time, the departure from the Gaussian noise and the intensities of the Gaussian and non-Gaussian noises. By calculating the transition rate W and the expression of the SNR of the system, we find that we are able to enhance the signal-to-noise ratio of the forest growth system as far as possible by means of adjusting the intensities of the Gaussian and non-Gaussian noises and the departure parameter.

2. The stochastic forest growth system driven by Gaussian and non-Gaussian noise

The model of a forest growth system [45] is written as the following differential equation:

$$\frac{dx(t)}{dt} = rx - \frac{r}{A}x^2, \tag{1}$$

this is an ideal equation without considering any fluctuations, where x is the number of trees, r denotes the growth rate of the trees, and A represents the upper limit of the forest development. Here $\frac{r}{A}$ stands for the crowded effect parameter of the forest. As a result, the deterministic potential corresponding to Eq. (1) is given by

$$V(x) = \frac{r}{3A}x^3 - \frac{rx^2}{2}. \tag{2}$$

In the absence of an external periodic force and noise terms, the fixed points of Eq. (1) strongly depend on r and A. We can easily obtain an unstable point $x_0 = 0$ and a stable point $x_s = A$.

Eq. (1) is an ideal deterministic differential equation excluding all kinds of fluctuations from the external environment. One should take into account a lot of restraining factors of the forest growth, such as the sunshine, temperature, humidity, soil, rain and climate, which all produce different types of unpredictable influences on the crowded effect parameter $\frac{r}{A}$ of the forest growth system. Therefore, the parameter $\frac{r}{A}$ should be modified as $\frac{r}{A} + \eta(t)$, meanwhile, some factors such as the interaction and competition effects of all individuals in the forest species can result in an additive noise $\xi(t)$. The periodic tidal action on the earth from the sun and the moon can also induce an external multiplicative periodic signal. Considering all these factors, Eq. (1) can be rewritten as

$$\frac{dx(t)}{dt} = rx - \left(\frac{r}{A} + \eta(t)\right)x^2 + \xi(t) + xf\cos(\omega t), \tag{3}$$

where $\xi(t)$ is a Gaussian white noise, and the noise term $\eta(t)$ possesses a non-Gaussian distribution with

$$\frac{d\eta(t)}{dt} = -\frac{1}{\tau}\frac{d}{d\eta}V_q(\eta) + \frac{1}{\tau}\varepsilon(t), \tag{4}$$

and

$$V_q(\eta) = \frac{Q}{\tau(q-1)}\ln\left[1 + \frac{\tau}{Q}(q-1)\frac{\eta^2}{2}\right]. \tag{5}$$

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