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Spectral method for non-Gaussian data generation by phase modeling: White noise phase versus structured phase

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ABSTRACT

This paper presents a spectral method for non-Gaussian data generation by phase modeling. Independent random phases have been used in a standard spectral method. Thus, the use of structured phases for non-Gaussian series in EARPG(1)/UPS is innovative but appears to conflict with the conventional modeling concept. This paper revisits the method and clarifies a difference in framework, which is apparently the white noise phase versus the structured phase but essentially a change in the whole framework. This paper rebuts the claim by Kumar and Stathopoulos in this journal (Suresh Kumar and Stathopoulos, 1999) that EARPG(1)/UPS using structured phases is unnecessarily complicated and inefficient compared with their EPG considering phase whitening, which is misleading in regard to the new modeling concept and the major simulation capability. The rebuttal clarifies that the new approach is based on a non-conventional time series modeling focused on spiky peak generation and a filtering ability of Fourier representation of the model. This new concept establishes a new spectral framework suitable for large-scale spiky time history simulation, permitting local non-stochastic variations and high-resolution sharpness in addition to the statistical properties of usual time series models. Simulation of wind-induced excursion loading is demonstrated.

1. Introduction

This paper is about a new spectral framework for random data generation based on phase modeling, which is different in concept and in simulation capability from the conventional independent-random-phase model. The idea is to use a linear time series model based on a non-conventional innovation variable and a spectral representation of the model. The new method represents a non-Gaussian spiky time history feature in the frame of a stationary stochastic process. This article is motivated by a critical review of the method by Kumar and Stathopoulos in this journal [1]. The review is apparently from the conventional stand point, for instance, requiring phase whitening, which is, however, an opposite concept of the phase modeling. The review is significantly misleading in regard to the major capability of the new approach. Thus, this paper includes a rebuttal. The rebuttal will clarify associated technical issues and how the non-Gaussian time history feature is obtainable and controllable within a stationary stochastic process frame.

The use of Fourier phase information is a new concept in spectral time series modeling. The concept developed a useful method for non-Gaussian data generation, called EARPG(1)/UPS (First-order Exponential Auto Regressive Peak Generation model with Uniform Phase Shift) [2], whose apparent advantage is the simulation capability of non-Gaussian spiky fluctuations by direct control of peaks through the Fourier phase. Thus, it does not require an additional process for non-Gaussian distributions which is necessary when a Gaussian model is used. Its performance was demonstrated in publications [3–5]. The publications have generated four discussion and reply articles [6–9]. The method has been extended to the multivariate [10] and the four-parameter model [11] and referred to other areas requiring non-Gaussian synthetic signals [12]. On the other hand, the new approach was reviewed as "extremely complex procedure", "unnecessarily three parameters", and "inefficient" [1,8], as well as "deterministic" [13]. Pertaining to the unjustified critique in the publication, this paper clarifies associated technical issues mainly caused by the use of the non-white-noise phase.

Independent random phase variables are an essential element in the construction of a stationary stochastic process from specified spectra [14,15]. The process has been widely used for random data generation in engineering applications, for instance, in [16–18]. For non-Gaussian distributions, an additional process has been

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employed such as a translation process. From this conventional point of view, the structured phase used in EARPG(1)/UPS appears to conflict with the theory. However, the new method is founded on a different modeling concept. The method employs a time series model and its spectral representation. It utilizes a concept of classical spectral analysis/synthesis/filtering. The spectral analysis enables the viewing of fluctuation data as a linear combination of random sinusoids. In the spectral synthesis by superposition of the sinusoids with various amplitudes, its time history feature depends on how the phases of the sinusoids are organized. A sharp large excursion in random fluctuations is an example which is highly dependent on the phase organization [2]. In the convention, the use of independent random phases is phase randomization in contrast to the phase organization. The results are Gaussian and not informative as far as a fluctuation feature is concerned. Thus, the independent phases are not useful for the simulation of a particular fluctuation feature. The phase should be properly modeled for the feature. However, the modeling is a challenge since correlations between the phase and time domain features are largely unknown. It is also difficult to define the feature in the conventional stochastic process framework. Such time history feature is best simulated by a physical (non-stochastic) model. Thus, the spiky feature generation by the phase modeling derived from a time series model, EARPG(1), is innovative [2,3] and some continued works [5,10,11] demonstrate how to model the phase for the fluctuation feature.

Kumar and Stathopoulus (1999, KS99 hereafter) in this journal [1] presented a similar approach. The approach is based on the same spectral frame but employs a different time series model, EPG (Exponential Peak Generation), and the phase whitening. KS99 claims that EARPG(1)/UPS using structured phases is unnecessarily complicated and inefficient compared with their EPG using the phase whitening. The critical review on EARPG(1)/UPS in KS99 significantly misleads the reader in regard to the new concept centered on phase modeling and the major simulation capability of generating spiky time history feature. Regarding the critique, this paper emphasizes four modeling aspects of the new approach: (1) the phase is derived from a time series model targeting a particular fluctuation feature, (2) the derivation necessarily induces a structured phase, (3) the structured phase does not affect "stationarity" of a generated time series in the new approach, (4) an autocorrelation in EARPG(1) is a fundamental requirement of the new approach.

The phase whitening in KS99 is an opposite concept of the phase modeling in EARPG(1)/UPS. EPG has no serial correlations which lacks the fundamental requirement. Therefore, KS's EPG and EARPG(1)/UPS are founded on a different framework and have a different simulation capability, even though they appear similar. This paper clarifies the difference which is apparently the white noise phase versus the structured phase and essentially the conventional versus the new. The spectral method by phase modeling provides a new framework for high-resolution simulation of local spiky fluctuation of Gaussian and non-Gaussian processes.

This paper is organized as follows. Section 2 deals with the critical reviews and rebuttal. Section 3 describes the new spectral model in comparison with the conventional model. Section 4 discusses associated technical issues and engineering application. This paper is concluded in Section 5.

2. Rebuttal to KS99's review on EARPG(1)/UPS

This section rebuts the critique raised by KS99. Section 4 in KS99 reviews EARPG(1)/UPS as follows.

"The noted limitations of this model are as follows: (1) the proposed parametric estimation procedure is extremely complex which makes the model inflexible, (2) the model is unnecessarily based on three parameters although only one is really important in simulating non-Gaussian properties, (3) the model is inefficient in achieving more than one desired non-Gaussian property, and (4) the model-induced phase correlation and its effects on the stationarity of the simulated signal has not been addressed. The adequacy of the model has only been shown for a time series of wind-induced pressures acting on a roof corner in an open exposure. In order to reduce these limitations, a modified simple and efficient model for the generation of phase is required. The model should induce various stationary non-Gaussian characteristics with the minimum number of parameters along with an efficient parametric estimation technique. Moreover, the efficiency of this methodology should be demonstrated for other building zones and flow characteristics."

In response to each itemized review, the author concludes and reconfirms: (1) the procedure is reasonably simple for the simulation of the spiky time history feature that is a major achievement, but denigrated in KS99; (2) all the three parameters are necessary for the time history feature; (3) the model is efficient for the simulation of both the time history feature and the consequent non-Gaussian statistics; (4) the addressing is not necessary since the new approach generates stationary data regardless of the correlation in the phase; (in the sentences following the itemized four reviews) the new approach is adequate not only for the particular area in the roof corner but also for the other cases demonstrated in KS99. Therefore, the above mentioned limitations are not limitations at all and the simple model is not required.

To realize the significant gap between the review and the author's conclusion, we deal with each item in detail. It will not only support the author's conclusion, but reveal how KS99's reviewing of the author's work is misleading. This section also clarifies some technical features of the new approach. As a result, it will point out a difference between the conventional spectral method and the new spectral method.

(1) The estimation procedure is not as simple as that using the phase whitening in KS99 because of the phase modeling associated with the spiky time history. However, it is reasonably simple for two reasons: it requires a first-order modeling similar to AR(1) for the parameter a, and utilizes generated simulation data for b and d. The use of data generation is a simple concept for selection of associated parameter values to match non-Gaussian statistics. Currently, an analytical estimation method for the non-Gaussian statistics is not available. The simulation-data-based procedure requires a large amount of data generation and calculation of the statistics over a range of parameters, which appears to make the procedure inefficient. However, in practice the range is significantly reduced to a small region where high-resolution investigation is possible. The procedure seems practical with currently available computing capability. While the analytical method is not available, the simulation-based estimation procedure is practically useful and robust. KS99 also employed the same procedure using simulation data for EPG's only one parameter b. In the author's approach, the additional parameter d leads to three-dimensional graphics in demonstration of the selection; and the first-order modeling for a requires an additional step. However, the additional processes do not make the procedure itself extremely complex.

(2 and 3) The parameter b dominantly affects the non-Gaussian statistics because of the particular signal generation mechanism among the three parameters: a, b, and d. However, it does not mean that the two others are unnecessary. As a result, the three-parameter model is inefficient. The three-parameter model targets the particular fluctuation feature as well as the consequent non-Gaussian statistics. All the parameters are necessary for both targets. This is clear in the development process of the model and the parameter