SPECTRAL KURTOSIS-BASED VIRTUAL INSTRUMENT FOR NON-DESTRUCTIVE ACOUSTIC EMISSION TARGETING OF TERMITES

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Abstract

In this paper, we present the results of operating a portable computer-based equipment conceived to perform non-destructive testing of suspicious termite infestations. Its signal-processing module is based in the spectral kurtosis (SK), with the de-noising complement of the discrete wavelet transform (DWT). The SK pattern allows the targeting of alarms and activity signals. The DWT complements the SK, by keeping the successive approximations of the termite emissions, supposedly more non-Gaussian (less noisy) and with less entropy than the detail approximations. For a given mother wavelet, the maximum acceptable level in the wavelet-decomposition tree, which preserves the insects' emissions features, depends on the comparative evolution of the approximations details' entropies, and the value of the global spectral kurtosis associated with the approximation of the separated signals. The paper explains the detection criterion by showing different types of real-life recordings (alarms, activity, and background).

Introduction

Biological transients gather all the natural complexity of their associated sources, and the media through which they propagate. As a consequence, finding the best method to get a complete characterization of the emission implies the selection of the appropriate model, which better explains the processes of generation, propagation and capture of the emitted signals. This description matches the issue of termite activity measurement.

The instruments for plague detection need to decrease subjectivity of the field operator. On-site monitoring implies reproducing the natural phenomenon of insect emissions with high accuracy. Thus, it is imperative to use a large storage device and highly sensitive probes with a selective frequency response. These features make their cost high, yet the success of the detection is not guaranteed.

Available detection methods are dependent on the detection of the excess of power in the signals; these are the so-called second-order methods. For example, the RMS calculation can only characterize the intensity, but provide no information regarding the envelope of the signal or the amplitude fluctuations. Another handicap of the second-order principle, e.g. the power spectrum, attends to the preservation of the energy during data processing and the eradication of additive noise lies in filter design and sub-band decomposition, like wavelets and wavelet packets.

In order to improve noise rejection and complete characterization of the signals, in the past ten years, a myriad of higher-order methods have been applied in different fields of science and technology, involving signal separation and characterization of non-Gaussian measurements. Concretely, the monitoring of rotating machines is also under our interest due to the similarities of the signals to be monitored with the transients from termites. Many time series of faulty rotating machines consist of more-or-less repetitive short transients of random amplitudes and random occurrences of the impulses.

The performance of a previous prototype, based in the time-frequency domain analysis of the kurtosis, was described in [1]. In this final improved version, the measurement method is based
on the interpretation of the spectral kurtosis graph, along with the wavelet analysis. At the same time, we use a simple data-acquisition unit, i.e., the sound card (maximum speed at 44.1 kHz), which simplifies the hardware unit and the criterion of detection.

This paper describes a method based in the spectral kurtosis (SK; related to the fourth-order cumulant at zero lags) to detect infestations of subterranean termites in a real-life condition (southern Spain). Wavelet decomposition is used as an extra tool to aid detection from the preservation of the approximation of the signal, which is thought to be more Gaussian than the details.

The interpretation of the results is focused on the peakedness of the statistical probability distribution associated to each frequency component of the signal, to get a measure of the distance from the Gaussian distribution. The SK serves as a twofold tool. First, it enhances non-Gaussian signals over the background. Secondly, it offers a more complete characterization of the transients emitted by the insects, providing the user with the probability associated to each frequency component.

The paper is structured as follows: in the following section a review on termite detection and relevant high-order-statistic (HOS) experiences sets the foundation. Then we make a brief report on the definition of kurtosis; we use an unbiased estimator of the SK, successfully used in [1]. Results are presented thereinafter. Finally, conclusions are drawn.

Subterranean Termites: Detection Project towards HOS

Termite detection has been gaining importance within the research community in the last two decades, mainly due to the urgency of avoiding the use of harming termiticides, and to the joint use of new emerging techniques of detection and hormonal treatments, with the aim of performing an early treatment of the infestation. A localized partial infestation can be exterminated after two or three generations of the colony's members with the aid of these hormones, which stop chitin synthesis. A chitin-synthesis inhibitor kills termites by inhibiting formation of a new exoskeleton when they shed their old one. As a direct consequence, the weakened unprotected workers stop feeding the queen termite, which dies of starvation.

The primary method of termite detection consists of looking for evidence of activity. However, only about 25% of the building structure is accessible, and the conclusions depend very much on the level of expertise and the criteria of the inspector [1-3]. As a consequence, new techniques have been developed to remove subjectivity and gain accessibility.

User-friendly equipment is currently used in targeting subterranean infestations by means of temporal analysis of the vibratory data sequences. An acoustic emission (AE) sensor or an accelerometer is fixed to the suspicious structure. This class of instruments is based on the calculation of the RMS value of the vibratory waveform. The RMS value comprises information of the raw AE-signal power during each time-interval of measurement (averaging time). This measurement strategy conveys a loss of potentially valuable information both in the time and in the frequency domain [1]. A more sophisticated family of instruments makes use of spectral analysis and digital filtering to detect and characterize vibratory signals [4]. Other second-order tools, like wavelets and wavelet packets (time-dependent technique) concentrate on transients and non-stationary movements, making possible the detection of singularities and sharp transitions, by means of sub-band decomposition.

HOS are widely used in several fields [5, 6]. The SK has been successfully described and applied to the vibratory surveillance and diagnostics of rotating machines [7]. In the field of insect detection, the work presented in [1] set the foundations of the present paper. The combined use of the SK and the time-domain sliding kurtosis showed marked features associated to termite emissions. In the frequency domain (sample frequency: 64 kHz), three frequency zones were identified in the SK graph as evidence of infestation; two in the audio band (which will be also checked in the present paper) and one in the near ultrasound (roughly equal to 22 kHz). In the present paper the sample frequency was fixed to 44.1 kHz and the sound card was directly driven by MATLAB. Results are presented in the user interface, shown in Fig. 1; in this
measurement situation, the raw data contains alarms from termite-activity signals. This is a clear example of positive detection.

The developed virtual instrument also calculates and presents the spectrum (top-right graph) and the raw data (bottom-left). The field operator adds therefore visual information to the classical audio-based criterion, which was subjective and expertise-dependent.

Fig. 1. The graphical user interface, which presents the results to the field operator. The SK is in the bottom-right corner.

Kurtosis, SK and De-noising Strategy via Wavelets

Kurtosis is a measure of the "peakedness" of the probability distribution of a real-valued random variable. Higher kurtosis means more of the variance is due to infrequent extreme deviations, as opposed to frequent modestly-sized deviations. This fact is used here to detect termite emissions in an urban background. Kurtosis is more commonly defined as the fourth central cumulant divided by the square of the variance of the probability distribution, which is the so-called excess kurtosis [1, 2, 8]:

\[
\gamma_4 \sim E [x^4] - 3 \gamma_2^2 = C_4(0,0,0) \tag{1}
\]

Ideally, the SK is a representation of the kurtosis of each frequency component of a process (or data from a measurement instrument, \(x_i\)). For estimation issues, we will consider \(M\) realizations of the process; each containing \(N\) points; i.e. we consider \(M\) measurement sweeps, each sweep with \(N\) points. The time spacing between points is the sampling period \(T_s\).

A biased estimator for the SK for a number \(M\) of \(N\)-point realizations at the frequency index \(m\), is given by:

\[
G_{2,X}^{N,M}(m) = \frac{M}{M-1} \left[ \frac{(M + 1) \sum_{i=1}^{M} |X_i^2(m)|^2}{\left( \sum_{i=1}^{M} |X_i^2(m)|^2 \right)^2} - 2 \right]. \tag{2}
\]

This estimator is the one we have implemented in the program code in order to perform the data computation and it was also used successfully in [1].

We expect to detect positive peaks in the kurtosis’s spectrum, which may be associated to termite emissions, characterized by random-amplitude impulse-like events. This non-Gaussian behavior should be enhanced over the symmetrically distributed electronic noise, introduced in the measurement system. Speech is perhaps also reflected in the SK, but not in the frequencies where termite emissions manifest. Besides, we assume, as a starting point, that non-Gaussian behavior of termite emissions is more acute than in speech. As a consequence, these emissions would be clearly outlined in the kurtosis spectrum. As a final remark, we expect that constant-amplitude interference is clearly differentiated due to their negative peaks in the SK.

To show the ideal performance of the estimator, described above and in [1], we show an example based in synthetics. A mixture of six different signals has been designed. Each mixture is the sum of a constant-amplitude sine of 2 kHz, a constant-amplitude sine at 9 kHz, a Gaussian-
distributed-amplitude sine at 5 kHz, a Gaussian-distributed-amplitude sine at 18 kHz, a Gaussian white noise, and a colored Gaussian noise between 12 and 13 kHz. Each mixture (realization or sample register) contains 1324 points. Negative kurtosis is expected for constant-amplitude processes, positive kurtosis should be associated to random amplitude and zero kurtosis will characterize both Gaussian-noise processes.

A simulation has been made in order to show the influence of the number of sample registers ($M$) in the averaged results for the SK graph, and to test its performance. Figure 2 shows a good performance because enough registers have been averaged ($M = 500$).

The mother wavelet Daubechies 5 has been selected as the most suitable mother wavelet, because of the highest coefficients in the decomposition tree. Given the mother wavelet, to show the process of selecting the maximum decomposition level in the wavelet tree, we have adopted a criterion based on the calculation of Shannon's entropy (information entropy), which is a measure of the uncertainty associated with a random variable.

We show this strategy via the following example, based on real-life data, like the recordings of Fig. 1, Figs. 3(a) and (b). The entropy of the approximations and the details are compared for each level of comparison and shown in Fig. 4.

![Fig. 2. Performance of the SK estimator over a set of synthetics.](image)

![Fig. 3 (a) A doubtful measurement situation without de-noising. (b) De-noising confirms activity.](image)
Fig. 4. Entropy evolution showing the optimum level [5].

By looking at the graph of Fig. 4, we see that at level 4, the entropy of the approximations is less than the entropy of the details. So, level 4 is in a sense, a point of inversion. No improvement is obtained for level 5, where the entropies are comparable. We can also see that the global difference of entropies increases towards zero, at level 5, as a complementary indication that further decomposition will not improve de-noising.

Experiment and Results

In this section we describe the experiment and measurements. A piezoelectric probe (model SP-1L, Acoustic Emission Consulting) is used in the final version of the instrument, and was described in detail in [1]. The sensor is connected to the sound card of a lap-top computer and the acquisition is driven by MATLAB, via the Graphical User Interface (see Fig. 1). The operator can select the acquisition time and the sample frequency (maximum 44.1 kHz). In the bottom-right corner of Fig. 1, the SK graph is presented. The user can also examine the raw data and the spectrum. Automatically, the instrument saves the acquired data (labeling the file with the date). Additionally, the operator can recall the stored files.

The key of the SK detection strategy used in this work lies in the potential enhancement of the non-Gaussian behavior of the emissions. If this happens, i.e. if an increase of the non-Gaussian activity (increase in the kurtosis, peakedness of the probability distribution) is observed in the SK graph, there may be infestation in the surrounding subterranean perimeter, where the transducer is attached.

In addition to the detection situation presented in Fig. 1, other situations are outlined. In Fig. 3(a), a doubtful measurement case is presented. Activity evidence is outlined only near 5 kHz. Once the wavelets have been applied, shown in Fig. 3(b), the enhancement near 5 kHz and 15 kHz confirms the detection.

Conclusion

Assuming the starting hypothesis that the insect emissions may have a more peaked probability distribution than any other simultaneous source of emission in the measurement perimeter, we have designed a termite-detection strategy and a virtual instrument based in the calculation of the 4th-order cumulants for zero time lags, which are indicative of the signals'
kurtosis. The instrument is actually in use by a Spanish company. An estimator of the spectral kurtosis has been used to perform a selective analysis of the peakedness of the signal. It has been shown that new frequency components gain in relevance in the spectral SK graphs. The main goal of this signal-processing method is to reduce subjectivity due to visual or listening inspection of the registers. This means that in a noisy environment, it may be possible to ignore termite feeding activity even with an *ad hoc* sensor because, despite the fact that the sensor is capable of registering these low-level emissions, the human ear can easily ignore them [1].

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