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A VIRTUAL INSTRUMENT FOR ACOUSTIC TERMITE DETECTION BASED IN THE SPECTRAL KURTOSIS

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Abstract: In this paper we present the operation results of a portable computer-based measurement equipment conceived to perform non-destructive testing of suspicious termite infestations. Its signal processing module is based in the Spectral Kurtosis (SK), whose pattern allows the targeting of alarms and activity signals. The estimator of the SK is proven previously using a set of synthetics. SK enhances the non-Gaussian behavior of termite signals, giving rise to a sensitivity improvement. As a complementary tool, wavelets confirm non-Gaussian behavior of termite emissions by keeping the approximation of the register, with less entropy.

Keywords: Acoustic emission, Higher-Order statistics, Termite detection.

1. INTRODUCTION

Biological transients gather all the natural complexity of their associated sources, and the media through which they propagate. As a consequence, finding the most adequate 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 measurement termite activity.

This paper deals with the improved equipment whose previous prototype's performance, based in the time-frequency domain analysis of the kurtosis, was described in [7].

In this final version, the measurement method is mainly based in the interpretation of the spectral kurtosis graph, along with the wavelet analysis, which is thought as an aid. At the same time, we use a simple data acquisition unit, the sound card (maximum speed at 44,100 Hz), which simplifies the hardware unit and the criterion of detection.

The instruments for plague detection are thought with the objective of decreasing subjectiveness of the field operator. On-site monitoring implies reproducing the natural phenomenon of insect emissions with high accuracy. As a consequence it is imperative the use of a deep storage device, and high sensitive probes with selective frequency characteristics. These features make the price paid very high, and still do not guarantee the success of the detection.

Regarding the procedures, the prior detection methods are based are very much dependent on the detection of excess of power in the signals; these are the so-called second-order methods. For example, the RMS calculation can only characterize the intensity, and does not provide information regarding the envelope of the signal nor the time fluctuations of the amplitude. Another handicap of the second-order principle, e.g. the classical power spectrum, attends to the preservation of the energy during data processing. Consequently, the eradication of additive noise lies in filter design and sub-band decomposition, like wavelets and wavelet packets.

As an alternative to improve noise rejection and complete characterization of the signals, in the past ten years, a myriad of higher-order methods are being applied in different fields of Science and Technology, in scenarios which involve signal separation and characterization of non-Gaussian signals. Concretely, the area of diagnostics-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.

This paper describes a method based in the spectral kurtosis (related to the fourth-order cumulant at zero lags) to detect infestations of subterranean termites in a real-life scenario (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 classical 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 spectral kurtosis 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 Section 2 a review on termite detection and relevant HOS experiences sets the foundations. In Section 3 we make a brief report on the definition of kurtosis; we use an unbiased estimator of the spectral kurtosis, successfully used in [7]. Results are presented in Section 4. Finally, conclusions are drawn in Section 5.

2. 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 urgent necessity 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 existing exoskeleton. As a direct consequence, the weakened unprotected workers stop feeding the queen termite of the colony, which dies of starvation, finishing the reproduction process, and consequently cutting any possible replacement of the members of the colony with a new generation.

The primary method of termite detection consists of looking for evidence of activity. But only about 25 percent of the building structure is accessible, and the conclusions depend very much on the level of expertise and the criteria of the inspector [5],[7]. As a consequence, new techniques have been developed to remove subjectiveness and gain accessibility.

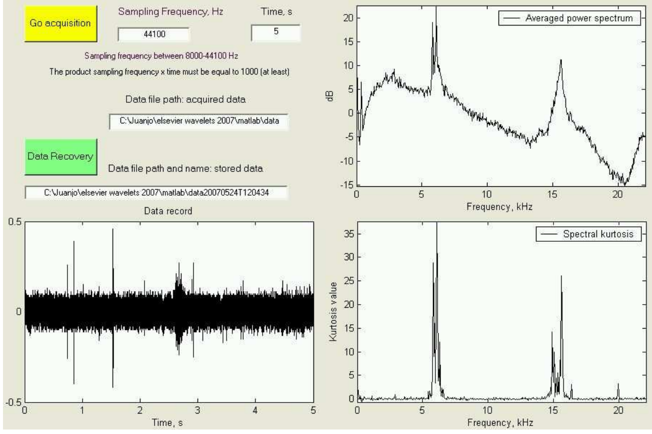
User-friendly equipment is being currently used in targeting subterranean insect infestations by means of temporal analysis of the vibratory data sequences. An acoustic-emission (AE) sensor or an accelerometer is fixed to the suspicious structure. This class of instruments is based on the calculation of the root mean square (RMS) value of the vibratory waveform. The RMS value comprises information of the AE raw 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 [7].

On the other hand, the use of the RMS value can be justified both by the difficulty of working with raw AE signals in the high-frequency range, and the scarce information about sources and propagation properties of the AE waves through the substratum. Noisy media and anisotropy makes even harder the implementation of new methods of calculation and measurement procedures. A more sophisticated family of instruments makes use of spectral analysis and digital filtering to detect and characterize vibratory signals [2].

Other complementary 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. The method has been proved under controlled laboratory conditions, up to a SNR=-30 dB [6].

Higher-order statistics are being widely used in several fields. The following are relevant due to the similarities of the problems they study. The spectral kurtosis has been successfully described and applied to the vibratory surveillance and diagnostics of rotating machines [1].

In the field of insect detection, the work presented in [7] set the foundations of the present paper. The combined used of the spectral kurtosis and the time-domain sliding kurtosis showed marked features associated to termite emissions. In the frequency domain (sample frequency 64,000 Hz) three frequency zones were identified in the spectral kurtosis 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 44,100 Hz and the sound card was directly driven by MATLAB, which presents the results in the user-oriented interface, which is forwarded in Fig. 1. In the measurement situation shown in Fig. 1, the time-raw data contains alarms an activity signals from termites. This is a clear example of positive detection.



Sampling Frequency, Hz: 44100

Time, s: 5

Sampling frequency between 8000-44100 Hz

The product sampling frequency x time must be equal to 1000 (at least)

Data file path: acquired data

C:\Juanjo\elsevier wavelets 2007\matlab\data

Data file path and name: stored data

C:\Juanjo\elsevier wavelets 2007\matlab\data20070524T120434

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

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

3. KURTOSIS, SPECTRAL KURTOSIS 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 by the way used in this paper 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, i.d. [4-5, 7]:

$$\gamma_{4,x} = E\{x^4(t)\} - 3(\gamma_{2,x})^2 = C_{4,x}(0,0,0) \quad (1)$$

Ideally, the spectral kurtosis 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.d. we consider M measurement sweeps, each sweep with N points. The time spacing between points is the sampling period T_s, of the data acquisition unit.

A biased estimator for the spectral kurtosis for a number M of N-point realizations at the frequency index m, is given by:

$$\hat{G}_{2,X}^{N,M}(m) = \frac{M}{M-1}\left[\frac{(M+1)\sum_{i=1}^{M}\left|X_N^i(m)\right|^4}{\left(\sum_{i=1}^{M}\left|X_N^i(m)\right|^2\right)^2} - 2\right] \qquad (2)$$

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 [7].

Regarding the experimental signals, 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 spectral kurtosis but not in the frequencies were 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 interferences are clearly differentiate due to their negative peaks in the spectral kurtosis.

To show the ideal performance of the estimator, which has been described in these lines, and also described in [7], 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 al 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-amplitudes 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. Fig. 2 shows a good performance because enough registers have been averaged (M=500). For $M < 100$, roughly, performance degenerates.

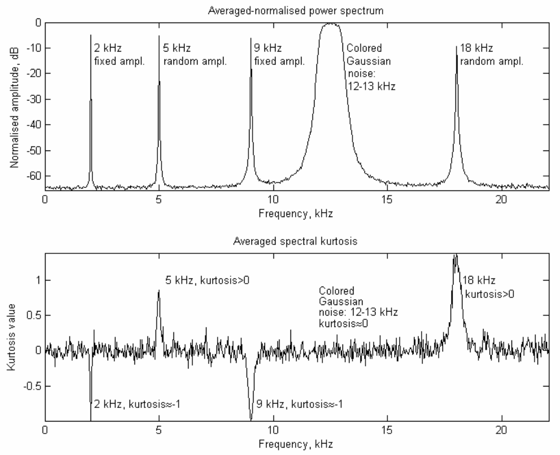


Fig. 2. Performance of the SK estimator over a set of synthetics.

The mother wavelet *Daubechies* 5 has been selected as most similar wavelet mother, because of the highest coefficients in the decomposition tree. given the wavelet mother, 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 *x*.

We show this strategy via the following example, based on real-life data, like the recordings of Fig. 1, Fig. 4 and Fig. 5. The entropy of the approximations and the details are compared for each level of comparison and shown in Fig. 3.

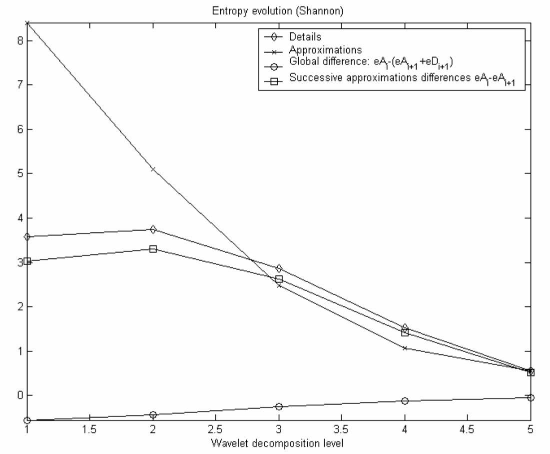


Fig. 3. Entropy evolution showing the optimum level (4).

By looking at the graph of Fig. 3, 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 very similar. 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 suppose progress in de-noising.

4. EXPERIMENT AND RESULTS

In this section we describe the experiment and present additional measurement situations. A piezoelectric probe-sensor (*model SP-1L from Acoustic Emission Consulting*) is used in the final version of the instrument, and was described in detail in [7]. 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 (GUI). The user interface was presented in Fig. 1. The operator can select the acquisition time and the sample frequency (maximum 44,100 Hz if the sound card is driven). In the bottom-right corner of Fig. 1, the spectral kurtosis 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 spectral kurtosis 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-measured in the spectral kurtosis 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 In Fig. 5 a doubtful measurement case is presented. Activity evidence is outlined only near 5 kHz. Once, the wavelets have been applied (shown in Fig. 5), the enhancement near 5 kHz and 15 kHz confirm the detection.

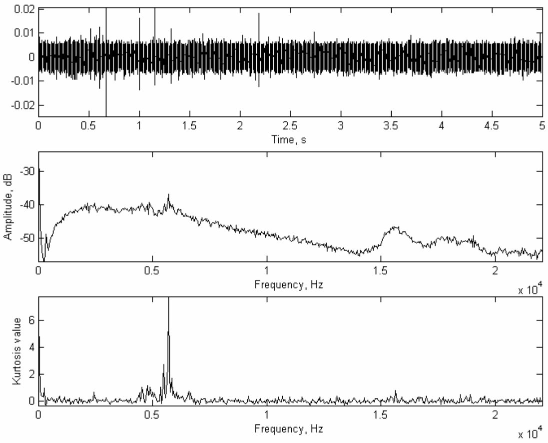


Fig. 4. A doubtful situation without de-noising.

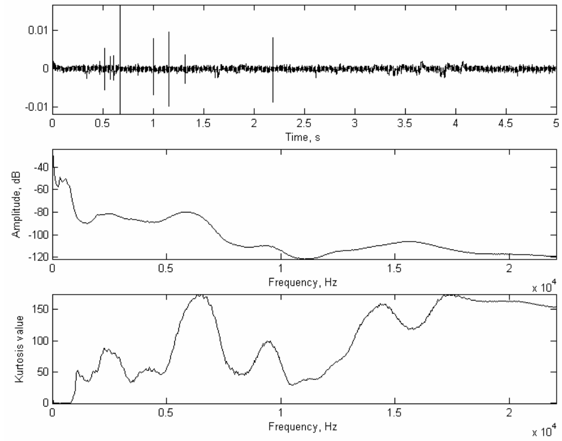


Fig. 5. De-noising confirms activity for data of Fig. 4.

5. 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 design a termite detection strategy and a virtual instrument based in the calculation of the *4*th-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 kurtosis graphs. The main goal of this signal-processing method is to reduce subjectiveness 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 register these low-level emissions, the human ear can easily ignore them [7].

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