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A novel measurement method for transient detection based in wavelets entropy and the spectral kurtosis: An application to vibrations and acoustic emission signals from termite activity ☆

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A B S T R A C T

This paper presents a novel non-destructive method for termite detection that uses the entropy of the continuous wavelet transform of the acoustic emission signals as an uncertainty measurement, to achieve selective frequency separation in complex impulsive-like noisy scenarios, with the aid of the spectral kurtosis as a validating tool. The goal consists of detecting relevant frequencies, by looking up the minima in the curve associated to the entropy of the difference between the raw data and the wavelet-based reconstructed version. By measuring the signal's uncertainty, the scales corresponding to the entropy minima, or pseudo-frequencies, manage to target three main types of emissions generated by termites: the modulating components (enveloping curve), the carrier signals (activity, feeding and excavating), and the communicating impulses bursts (alarms). The spectral kurtosis corroborates the location of the entropy minima (optimum uncertainty) matching them to its maxima, associated to frequencies with the highest amplitude variability, and consequently minimizing the measurement uncertainty. The method is primarily conceived to cover the acoustic-range, in order to acquire signals via standard sound cards; a broaden high-frequency study is developed for the assessment, and with the added value of discovering new and higher frequency components of the species emissions. The potential of the method makes it useful for myriads of applications in the frame of nondestructive transient detection.

1. Introduction

Real-life measurement scenarios are quite different from controlled lab experiences, where unexpected deviations from the forecasted behavior are not frequent and the uncertainty lies within a controlled range, usually established by international measurement standards. Nevertheless, Nature's modeling should account with unexpected non-stationary non-linearities, whose complexity would induce to use accurate models, in order to

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get more understandability of the phenomena. What is more, sources of uncertainty are not always known, and they usually present abruptly, without obeying a concrete probability law and with important consequences [1,2].

Increasing computational complexity does not guarantee the success in modeling. By one side, in the case of achieving an hypothetical perfect model, their implementation in measurement equipment would be technically unfeasible. Secondly, it is assumed that the default characterization for the measured data sequences is sustained in the traditional statistical density functions (e.g., the Gaussian distribution) and numerous second-order statistics. But these tools do not comply with infrequent phenomena and non-linear fluctuations [1,2]. In fact, uncertainty calculations for measurement equipment also relies on the hypothesis for the statistical distribution that best characterizes the original data. As a consequence, for highly non-stationary data, minimizing the degree or disorder may represent the measurement procedure that most fits the scenario of chaos, nonlinearity and infrequent phenomena.

The main goal of this work is to use the entropy of the differential acoustic emission signals (original minus a wavelet-based reconstructed version) to monitor the measurement uncertainty; the minimum-chaos frequencies indicate the presence of relevant information, significative and proper of the phenomenon under study as it is related to minimum energy states.

In the case of termite detection, the low-frequency components in the differential entropy pattern correspond to the time-enveloping curve of the emissions; the alarm signals predominate in the mid zone of the frequency range, and in the higher zone of the spectrum, the predominant components are related to feeding and excavating activities; and it is precisely this zone that gathers special interest because it is the key of detection procedure, consisting of low-level-amplitude signals which constitute the most frequent emission of the species.

The theoretical cross-validation of the procedure pivots in the spectral kurtosis, which has been successfully used to detect high-variability phenomena in various fields of Science and Technology [3], and in the context of termite detection, by the authors in [4,5]. The maxima in the spectral kurtosis graph indicate spurious signals with an amplitude which varies with time. The higher the kurtosis, the higher variability and the chaos associated to this amplitude, which is generally non-Gaussian distributed.

This methodology is conceived for implementation in computers and user-friendly technology, e.g. using the sound card, sampling at 44,100 Hz. Nevertheless, a high frequency analysis is performed in this work, serving as the best validating tool. The high-freq. acquisition was performed by a portable data taker at 625,000 Hz. It is shown that the low-frequency entropy pattern is contained within the broaden spectrum (a frequency subset), which is exhibited by the curve of the entropy vs. the frequency. It is precisely this pattern that characterizes the phenomenon under study; its different frequency bands provide information of the different possible activities of the animal species and the media through which the elastic and acoustic waves propagate.

Regarding the computational tools, the work points out a two fold idea. By one side, the backward use of a second-order statistic, Continuous Wavelet Transform (CWT) and entropy, as valid indicators. On the other hand, the combination of the CWT-entropy and the SK result in a powerful tool for targeting non-linear and non-stationary phenomena.

The paper is structured as follows. A brief introduction to termites and the problem of early detection is outlined in Section 2, focussing in a concrete species via graphical examples; Section 3 performs a revision of the wavelets, focussing in the context of the application. Section 4 describes the entropy-based method through basic examples based in synthetics, and the hardware for the data acquisition stage. Section 5 presents the main results, showing graphical examples of real-life analysis. Finally, the conclusions and the summary of the study are drawn in Section 6.

2. The problem of termite detection

Termites are eusocial (highest level of social organization) insects that are classified at the taxonomic rank of the order *Isoptera*, and recently accepted as *Termitidae*. Dividing labor among castes, mostly feed on dead organic material, generally in the form of wood, leaf litter, soil, or animal dung.

Social insects like termites live in colonies, that number from several hundred to several million. Colonies use decentralized, self-organized systems of activity guided by swarm intelligence which exploit food sources and environments unavailable to any single insect acting alone. A typical colony contains nymphs (semimature young), workers, soldiers, and reproductive individuals of both sexes, sometimes containing several egg-laying queens.

Reticulitermes is a termite genus in the family *Rhinotermitidae*; *Reticulitermes Grassei* is in southwestern France, northwestern and southern Spain and Portugal, and is the genus object of the study in the present work. Nevertheless, the results can be easily extrapolated to other termites.

About 10% of the estimated 4000 species (about 2600 taxonomically known) are economically significant as pests that can cause serious structural damage to buildings (wood structures), crops or plantation forests. In some countries, like the USA cause more damage to homes than storms and fire combined. Most of the damage (90%) is done by subterranean termites. These costs could be significantly reduced through earlier detection of infestations.

Regarding the acoustic emissions, from the behavioral perspective, we can distinguish between activity signals (associated to feeding and excavating) and the alarms (burst of 4 or 5 impulses depending on the species), which are produced in presence of a threaten and is usually known as “head banging”. Fig. 1 reproduces a single alarm pulse, along with significant activity impulses [6–12].

The frequency content of the alarms falls into the audio band, while feeding and excavating may reach much more