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Short communication

Continuous monitoring of beehives' sound for environmental pollution control

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ABSTRACT

The massive use of pesticides and herbicides to increment the agriculture production can produce severe environmental impacts. This implies the need of new methods to monitor and control the use of chemical agents. An alternative to traditional sampling methods is the use of insects to act as a biological distributed sensor in order to monitor the presence of pesticides in the neighbourhood. Specifically, several authors have proposed the use of the beehive as a distributed sensor. To evaluate critical changes in the beehive behaviour, the sound patterns are analysed. In this work the guidelines used to develop a remote monitoring system in order to detect abnormal changes in the sound patterns in hives are presented. The evolution of the frequency spectrum sampled in four temporal windows is proposed to monitor the beehive health. Experiments to determinate the frequency band and the frequency resolution are presented for the case of *Apis mellifera*. Using these guidelines a complete monitor system was developed and constructed.

1. Introduction

In many developing countries, the productive matrix is changing to introduce more technology in order to obtain a better production performance. This is the case of Argentina, Uruguay and the south region of Brazil, where the traditional extensive livestock was progressively changed by intensive agriculture (Wingeyer et al., 2015). However, these new practices often use great quantities of pesticides and agrochemicals introducing several negative environmental effects (Carriquiriborde et al., 2014). The evaluation of the agrochemical products effectively applied is not a simple task. For instance, new methods to prevent the excessive application of agrochemicals are needed to improve control regulations. The precise determination of chemical components must be done using analytical techniques. In the last years, the use of insects and birds as biological monitors to evaluate environmental changes, has been proposed for early detection of pollution (Geogh, 1998; Koskimies, 1989). Specifically, the use of the honeybee as a distributed sensor is proposed by several authors (Zacepins et al., 2015; Chauzat et al., 2011; Balayiannis and Balayiannis, 2008; Ghini et al., 2004; Kezic et al., 2002; Porrini et al., 1998). Honeybees fly in a neighbourhood of 3 km around the beehive seeking food. This way, the agrochemical products localized in this area can be transported by the bees and introduced to the hive. The relationship between chemical traces in the hive and the presence of the same products in the neighbourhood is a research topic in this field (Pareja et al., 2011; Naggara et al., 2015; Niell et al., 2014). However, analytical techniques to determine the chemical traces are often difficult and expensive. For that reason, the use of an approximate pre-sorting to reduce the number of analytical test is highly desirable. The main idea is to measure an indirect parameter in the hive that alerts about abnormal changes. At the end, the presence of contaminating agents must be determined by analytical techniques, but they are applied on specific places with high probability of containing pollutants (Celli and Maccagnani, 2003). Sound patterns in the beehive can be used as a health indicator of the bee's community. They are interesting markers to evaluate abnormal changes in the beehive, since its measure can be easy and inexpensive, and can be applied in a large number of hives to make a continuous monitoring (Lefebvre and Beattie, 1991; Ferrari et al., 2008; Mezquida and Martínez, 2009; Bencsik et al., 2011; Eskov and Toboev, 2011; Ward, 2012; Sánchez et al., 2015). There are two main aspects to implement the beehive

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health monitoring using sound patterns. The first is the determination of the relevant characteristics in the sound pattern, minimizing the amount of information to be recorded and transmitted. In this paper, the more relevant characteristics of the sound pattern are analysed and the guidelines to design an autonomous monitoring system are given. Some details of the practical implementation done by the authors are also presented. The second aspect to be considered is the relationship between changes in the sound pattern and the behaviour of the bees inside the hive. Up to now this is an open question for which more research is needed and it is a future work that will be addressed with the proposed system.

2. Material and methods

2.1. Sound pattern analysis

In the first analysis stage, sound patterns on three beehives of *Apis mellifera*, the most common species of bees in Uruguay, were examined over two month. This first set of tests was made using a portable personal computer and recording the sound signals using the standard microphone input. The objective of the tests was the characterization of the system in order to design a dedicated electronic for continuous monitoring of the sound patterns. A capacitive microphone was placed inside the hive in a protected compartment, to prevent that the microphone be clogged with beeswax. Some authors propose the use of cellular phones to record the sound patterns in the hive (Favre, 2011). In some situations this may be suitable, however in this case is highly recommended the use of a fix microphone in order to reduce the variations in the sound pattern introduced by placing the microphone in different places. Since the number of bees in the hive can be in the order of tens of thousands, the sound emitted by a single bee does not matter. Only the global pattern produced by the community is relevant in the determination of behaviour changes. The problem is similar to determine the feelings of the audience attending a football game by recording the sound from the outside of the stadium. The sound has global characteristics that can be used to determinate the number of goals, for example. The first decisions to be made in the design of such system are the sampling frequency and the temporal window to acquire the signals. Fig. 1 shows the spectrum of an example sound signal recorded in the hive.

There are four main parameters to fix for the recorded signal: the sampling frequency, the temporal window, the number of samples and the number of bits of the vertical resolution. The sampling frequency Fs is the inverse of the interval between two consecutive samples of the recorded signal. Then, we need Fs samples for each audio signal recorded second. Fourier Theory for signals tells us that each signal is formed by the sum of sinusoidal components. The amplitude and the phase of these sinusoidal components can be obtained by the Fourier Transform of the signal (Oppenheim et al., 1997). This structure, amplitude and phase as a function of frequency, is often named as the frequency spectrum of the signal. When the phases are not relevant, as in our actual case, the spectrum only refers to the amplitudes of the different frequencies present in the signal. The sampling frequency is related to the maximum frequency in the spectrum, since this maximum frequency is half of the sampling rate. The temporal window Tw is the duration of the recording interval in seconds. The number of samples Ns can be obtained as the product Ns = Tw · Fs. For higher sampling frequency or wider temporal window, more memory and transmission bandwidth is needed. The vertical resolution is the number of bits used in the digitalization; for example using 8 bits the signal is divided in steps of $1/2^8$. The present example was acquired using the half of the audio standard sampling frequency Fs = 22,050 Hz. The temporal window was 30 s and the signal is digitized using 16 bits. Fig. 1 shows the frequency spectrum of the signal; each component of this spectrum is related to the energy associated to this frequency in the original sound. It can be seen that the signal has no relevant spectral information beyond 1 kHz.

This limited bandwidth is verified over hundreds of signals acquired in different days and at different hours. Then, the sampling frequency is limited at 2 kHz, in order to represent up 1 kHz in the acquired signal. The second decision to be made is the temporal window. It determines the resolution in the frequency spectrum f as

$$\Delta f = \frac{F_s}{N_s - 1} = \frac{1}{T_w} \quad (1)$$

Then, for wider temporal window, a better resolution in frequency is obtained. To determinate the frequency resolution we must first consider the relevant characteristics of the signal in order to follow the behaviour changes. Several authors use the temporal representation of the signal to extract conclusions about the behaviour of the bees (Wenner, 1962; Hrncir et al., 2008). However, this representation may be useful in the case of the pattern emitted by a single bee. In our case, the pattern is the sum of a multitude of bees acting asynchronously. That is, since bees emit sounds in the

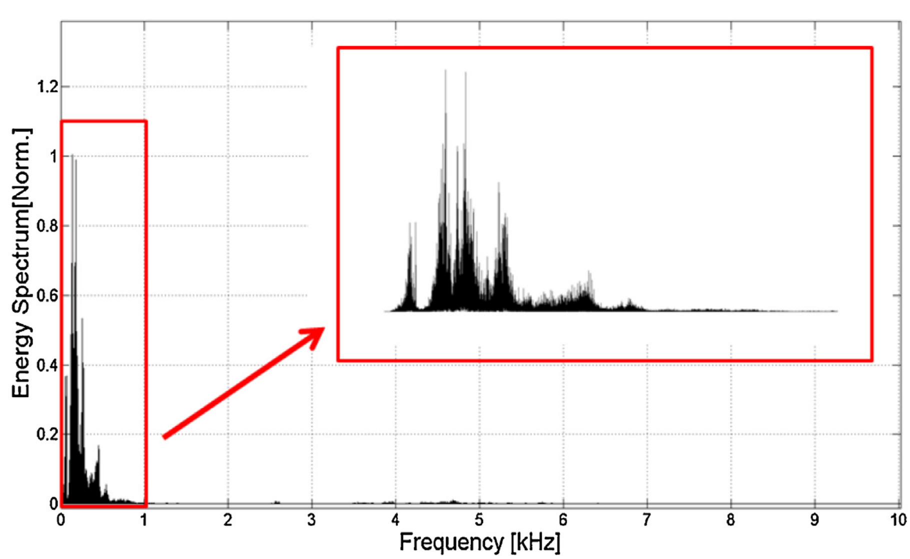

Fig. 1. Energy frequency spectrum. Note that most of the energy is concentrated in the 1 kHz band.