Journal of Cultural Heritage 16 (2015) 338–343

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Original article

Acoustic emission to detect xylophagous insects in wooden musical instrument

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ARTICLE INFO

Article history:
Received 6 January 2014
Accepted 9 July 2014
Available online 22 August 2014

Keywords:
Acoustic emission
Xylophagous insect detection
Wooden cultural heritage
Diagnosis
Classification
Cyclododecane

ABSTRACT

Acoustic emission monitoring was applied for the detection of xylophagous insects and more specifically *oligomerus* and relative species in wooden cultural heritage musical instruments kept in European museums where the temperature and hygrometry are controlled according to International Council of Museums (ICOM) rules. Using broadband high frequency sensors [75–1000 kHz] and a high level of amplification to compensate the acoustic attenuation in wood, it is possible to detect the presence of very small larvae (1–2 mm length) in a wooden object. Different coupling materials which respect conservation rules have been tested to fix the sensor to the artefact with an optimized signal to noise ratio. Such coupling materials must not damage the surface of the object and must enable a reversible operation. Since the acoustic signal (frequency and amplitude) depends on the distance between the sensor and the source, robust data processing based on an orthogonal linear transformation is then applied to the recorded signals to distinguish insect signals from ambient noise.

1. Research aim

Diagnosing the presence of xylophagous insects in cultural heritage artefacts is a concern for many curators in European museums or in private collections, especially when the climate is regulated (according to the ICOM rules, $T = 20 \pm 2\,^{\circ}C$ and $H\ (\%) = 55 \pm 5\%$). For well-equipped collections, once a risk appears, the objects are treated against pest infestation by non-destructive methods (passive or active anoxia with oxygen absorber bags or nitrogen income). This technique is expensive, requires a long treatment period and is sometimes unnecessary when non-infested objects are treated. Our research aims at developing an acoustic emission detection system – consisting not only in an acquisition system but also in effective data processing – sensitive enough to detect the low activity of the xylophagous larvae while respecting the reversibility principles and museum deontology.

2. Woodboring beetles and acoustic emission – state of the art

Woodboring beetles that damage wooden cultural heritage objects are primarily members of the Anobiid family. They are characterized by a capacity to digest dry wood (xylophagous) and their ability to dig galleries inside the wood [1]. The larval stage is the most damaging: during this stage they feed exclusively on wood, tunnelling into the substrate. An average life cycle takes one to several years, depending on temperature, humidity and the nutritional value of wood [2].

Detecting the activity of these larvae is difficult because tunnelling and development occur entirely below the wood surface. The close relationship between larvae and wood allows us to use the characteristic of wave transmission in wood to follow insect activity through acoustic emission.

Acoustic emission (AE) monitoring is an important non-destructive tool to track the evolution of damages in materials and has also been used in wood science [3]. Many studies deal with the relationship between the stress level in wood under flexural loading and AE energy due to the fracture process [4] using ultrasonic sensors with a nominative frequency of 200 kHz. Aicher et al. [5] have shown that using several ultrasonic sensors it was possible

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http://dx.doi.org/10.1016/j.culher.2014.07.001
1296-2074/

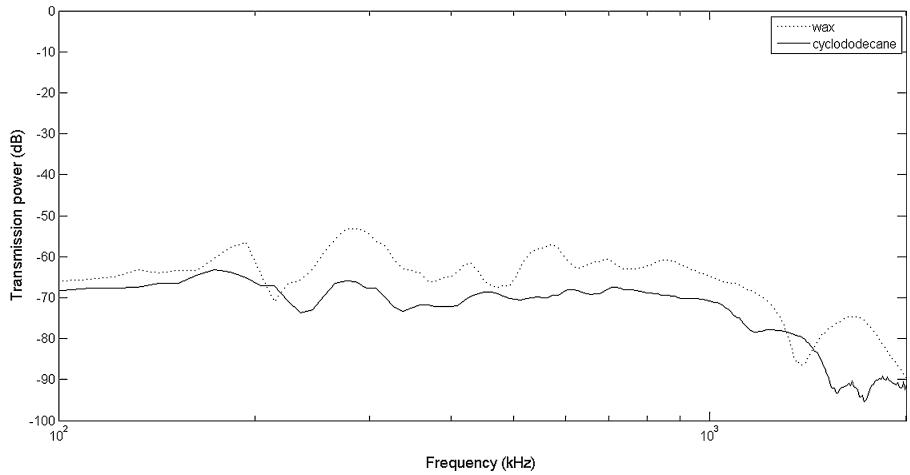

Fig. 1. Comparison of acoustic transmission coefficient using traditional wax and cyclododecane for ultrasonic waves.

to locate the damage before the rupture. The influence of external parameters has been also reported, especially the variation in ambient relative humidity [6–9]. Moreover, analysing the acoustic energy level has led to differentiating micro-fractures (low energy) from surface shrinking during drying [9]. AE has been used to monitor the natural degradation of wood due to termite activity [10–12] or fungal infestations [13].

However, in spite of its characteristics and popularity, AE has been very little used to monitor cultural heritage objects. One exception concerns the tracking of the stress induced by climate variations in wooden paintings [14,15]. The acoustic energy is correlated to the temperature change.

The coupling materials needed to fix the ultrasonic sensor on the cultural woodcraft have to be carefully chosen. Indeed, to obtain a high signal to noise ratio, the sensor has to be perfectly glued to the surface due to the high attenuation coefficient of the ultrasonic wave in wood.

Acoustic detection tests were conducted on *Anobium punctatum* and related species [16,17] using audio frequency range sensors (20 Hz–10 kHz) but the signal to noise ratio was too low to robustly detect insect activity.

In this paper, detection of woodboring beetles is presented using AE after proposing a material adapted to fix an ultrasonic sensor to a wooden musical instrument or to woodcrafts in general. For that, preliminary experiments were conducted in laboratory conditions using an infested piece of wood and a blank sample. In the following section, a first subsection is dedicated to the choice of a coupling material. The challenge for cultural heritage applications is to propose a material which is both acoustically effective and removable. We then present different labelled signals that were recorded and processed with a principal component analysis (PCA). We have both signals that are due to the insect activity (before and during the anoxia treatment) and signals that were recorded on the blank sample. These last signals correspond to noise signals: electronic noise and the noise from the anoxia treatment, which is due to the increase in temperature and humidity from the oxygen bags. Finally, the last section will detail the application of the device in a museum where the temperature and humidity content are quite stable according to the ICOM rules.

3. Materials and method

3.1. Coupling material

The limited use of AE to trace damages (natural or mechanical) in wooden heritage objects could be due to the material coupling. Indeed, in classical AE processes, very strong adhesives are used, such as cyanoacrylate. The advantage of these adhesives is that they provide a high transmission of the acoustic signal between the support and the sensor. However, these adhesives do not respect conservation deontology principles since they are not reversible. In some cases, specific wax could be used, but this solution is not suitable in the case of fragile paintings or varnished layers, where the wax removal could also remove the top layer. Since cyclododecane sublimates at room temperature with continued air exposure, it has been used for more than ten years in short-term applications, as an adhesive [18], a moulding material [19], barrier layer [20], or consolidant [21]. Sublimation negates the need for later removal of the adhesive, and temporary treatment with cyclododecane should not interfere with subsequent study, analysis, or treatment.

Cyclododecane has then been chosen as a coupling material to fix the ultrasonic sensors to wood artefacts. To validate the ultrasonic (US) transmission power of this material, two US panametrics (1 MHz and 2.25 MHz resonant frequency) sensors have been glued on each side of a 2 mm thick wooden plate, first with a traditional

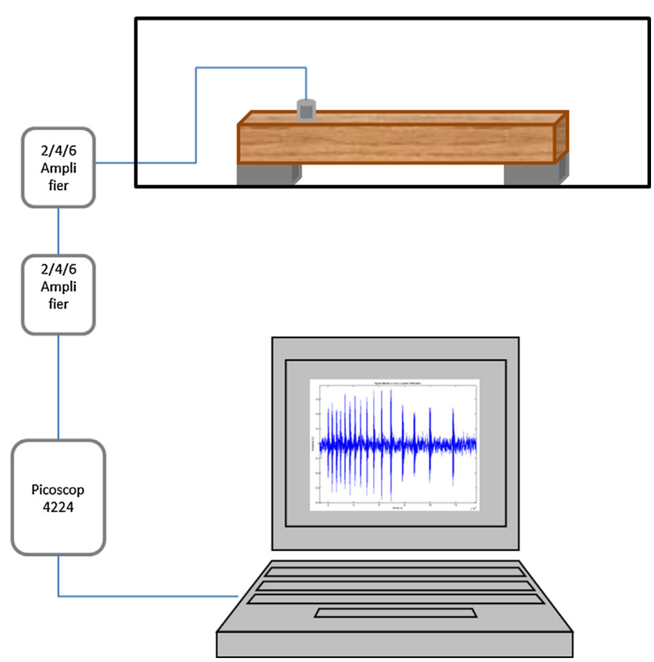

Fig. 2. Acoustic emission (AE) set up for tracking xylophagous activity.