DOI: 10.61782/fa.2025.0284

DETECTION AND SPATIAL LOCALIZATION OF XYLOPHAGOUS INSECTS IN WOOD STRUCTURES WITH ACOUSTIC ARRAYS

Lara del Val[1*] **Alberto Izquierdo**[1] **Juan J. Villacorta**[1]
Roberto D. Martínez[2]
[1] Department of Signal Theory and Communications and Telematics Engineering, University of Valladolid, Spain
[2] Agricultural Engineering School, University of Valladolid, Spain

ABSTRACT

This work presents a system for the detection and localization of the presence of active larvae of xylophagous insects inside wooden structures using an extensive array of MEMS microphones. This system, in a first phase, continuously detects the activity of the larvae by means of frequency filtering and a sliding energy estimator, and subsequently, in a second phase, generates a set of segmented signals of short duration with which it obtains the spatial location of the larvae, using the basic delay-sum beamforming algorithm. Tests performed with *Hylotrupes bajulus L.* larvae (house longhorn beetle) inside pieces of *Pinus syilvestris L.* wood demonstrate that detection and localization of multiple larvae is possible, as well as tracking their internal trajectory.
The aim of this system is to help control unintentional infestations in the international timber trade, as well as in museums and other places where the protection of heritage timber is necessary. With this type of systems, selective, specific and localized treatments could be carried out to combat these infestations and verify their success.

Keywords: *MEMS microphone array, beamforming, xylophagous detection and localization.*

[*] ***Corresponding author***: *lara.val@uva.es*

1. INTRODUCTION

The degradation of structural timber by xylophagous insects is a global issue, as wood is naturally susceptible to decay fungi and insect attacks. Preventive and curative treatments are costly worldwide, in an economic, environmental and patrimonial sense. In particular, *Hylotrupes bajulus L.* (House Longhorn Beetle) causes significant damage to structural wood, carpentry, and furniture [1-2].
Traditional detection methods include visual inspection, listening for sounds made by larvae, and using complex instrumentation [3-4]. Acoustic emissions (AE), elastic waves caused by fractures or friction in solid materials, are also used to study material fatigue and insect attacks in wood [5-6]. Recent advances incorporate signal analysis and Artificial Intelligence [7], though sensor placement and larvae inactivity pose challenges. In this way, commercial remote sensing applications are emerging [8].
The aim of the work is to develop a low-cost, non-contact technique using a MEMS microphone array to detect and accurately locate active House Longhorn Beetle larvae inside wood. This system targets infections in museums, international timber trade, and infected wood assembly, allowing for selective treatments and verification of their success.

2. ACOUSTIC SYSTEM

The developed acoustic system comprises three components:

- An array of MEMS microphones for acoustic sensing.
- An FPGA/Processor-based system for acquisition and pre-processing.
- A PC application for analysis, detection, and visualization.

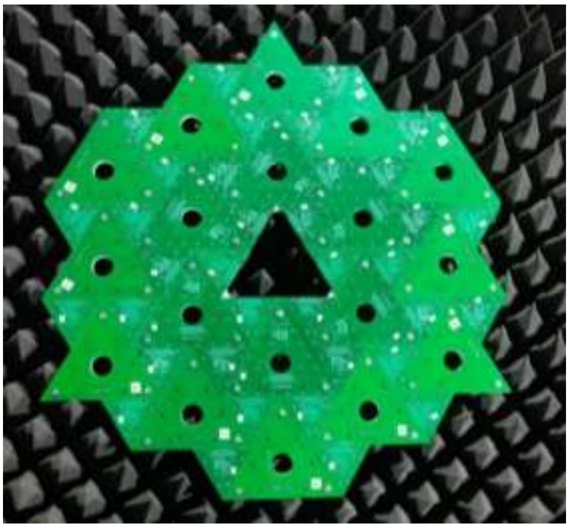

Figure 1. Array of MEMS microphones.

2.1 Array of MEMS microphones

In this study, a planar array of 486 SPH0641LU4H-1 digital MEMS microphones of Knowles [9], with a spatial aperture of about 35 cm, in both spatial dimensions, has been used. This 2D array is shown in Fig. 1.

For practical purposes (digital band-pass filters implementation), the frequency band of interest has been defined between 13 kHz and 23 kHz. This frequency band takes advantage of the high sensitivity to high frequencies of the selected MEMS microphones, and it also reduces the contribution of ambient noise by discarding low frequencies.

Considering this defined working frequency band, and establishing a maximum angular resolution of 10º and a maximum angular excursion of 50º for the acoustic beams, it can be inferred that the array beamwidths vary between 2.6º and 10º.

Together with the array, the delay and sum beamformer technique, under near-field conditions [10], has been employed. So, for this reason, a spherical propagation of the signal has been assumed.

2.2 Acquisition and processing system

3 interconnected and synchronized 9607 sbRIO platforms [11], of National Instruments, have been used to capture the signals obtained by the microphones of the array. This sbRIO platform is an embedded single-board controller with an FPGA Zynq-7020 and a dual-Core 667 MHz processor. In this system, 81 of the 96 digital input/output (I/O) lines of the FPGA have been used, in a multiplexed way, as the connection interface with 162 MEMS microphones of the array. This is the reason why 3 sbRIO platforms are needed in the system, to connect the whole 486 microphones of the array. The other FPGA I/O lines are used to generate the clock for the synchronization.

2.3 Software: analysis, localization and visualization

A specific software, developed using LabVIEW 2021 programming language, handles the following tasks, running on a Personal Computer:

- Control of the synchronized capture operations of the 3 acquisition platforms.
- Detection of larvae activity.
- Storage of the detected acoustic signals produced by the larvae when bite wood.
- Implementation of beamforming algorithms to localize the position of the detected sounds.
- Visualization of the localized positions.

2.4 Test set-up

The test setup, shown in Fig. 2, was implemented inside an anechoic chamber, placing the acoustic system parallel to the wooden frame, centered with respect to the wooden parts, and 600 mm apart. This wooden frame was made up of 4 beams of wood measuring 90x140x1200 mm of Scots pine (*Pinus sylvestris L.*), where 6 larvae of *Hylotrupes bajulus L.*, weighing between 0.22 g and 0.35 g, were implanted, as it is shown in Fig. 3.

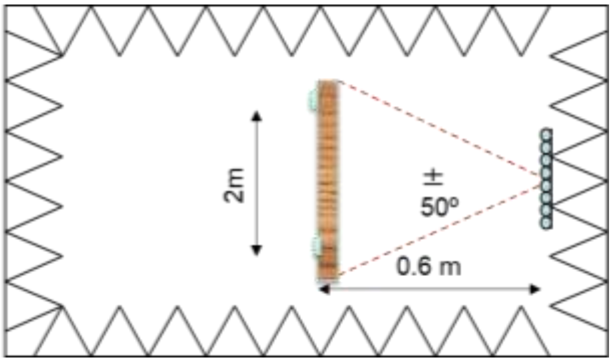

Figure 2. Test set-up.

2.5 Time and frequency characterization of insect bites

The first idea that must be considered is that insects generate a wide variety of sounds for different purposes, and this work is interested in those sounds related with bites. And the second one is that the composition of the wood affects the generated sound.

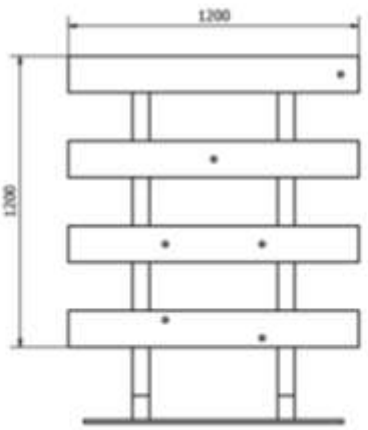

Figure 3. Test wooden frame with 6 larvae positions.

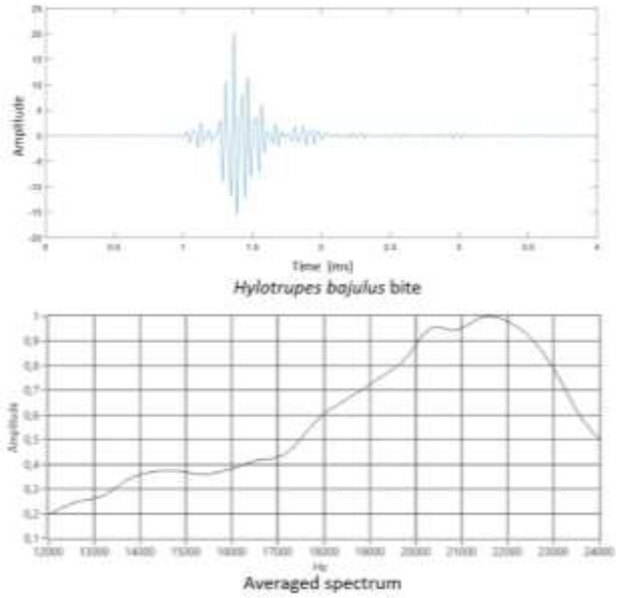

Figure 4. Larvae bites signals in time (above) and in frequency (below) domains.

During the acquisition phase, which lasted 2 months, more than 50,000 detections were generated by the 6 larvae. These detected signals were characterized in the time and in the frequency domain. In Fig. 4 (above), it is shown that the larvae bites had a typical duration of 1 ms. Looking at the averaged spectrum of the bites, shown in Fig. 4 (below), it can be observed that the system response is maximum at high frequencies, between 20 and 23kHz.
Due to having hundreds of microphones working together in the array of the system, its gain is 26dB, allowing the detection and localization of week acoustic signals. Besides, the angular resolution of the array improves, as the working frequency gets higher. These are the two reasons why the overall system sensitivity is very high.

3. PROCESSING ALGORITHM

The implemented processing algorithm is shown in Fig. 5.
First, the system acquires, continuously, samples of acoustic signals of 22.5 ms duration, using a sampling frequency of 50 kHz, for each of the 486 microphones of the array. This step also includes a digital anti-aliasing 24.5 kHz low-pass filter.
Then, each captured signal is filtered by a digital FIR filter, with a pass-band between 13 kHz and 23 kHz.
In the next step, to detect if there is activity of any of the larvae, the sliding energy for the filtered signals is calculated over a window of 2 ms, and after that, the average of the energy estimators is calculated.

The averaged energy estimated is compared with an appropriate threshold, and if it exceeds it, the position of the first maximum of the energy is searched for a segmentation. In the segmentation, for each of the 22.5 ms filtered signals, a segment of 2 ms duration is extracted, containing the acoustic signal emitted by the larva.
After the segmentation, using a nearfield Delay and Sum beamforming technique, an acoustic image is constructed, from the generation of 61 × 61 beams, to analyze the plane containing the 4 wooden beams under analysis.
Finally, the position of the maximum of the acoustic image is obtained, which corresponds to the location of the detected larva.

4. RESULTS

Despite there were 6 larvae implanted in the 4 wooden beams, 7 zones where the maximums of the acoustic images are concentrated, were obtained, as it can be observed in Fig. 6. Fig. 6 also shows variable dispersions for each of the larvae, due to their movements and activity.

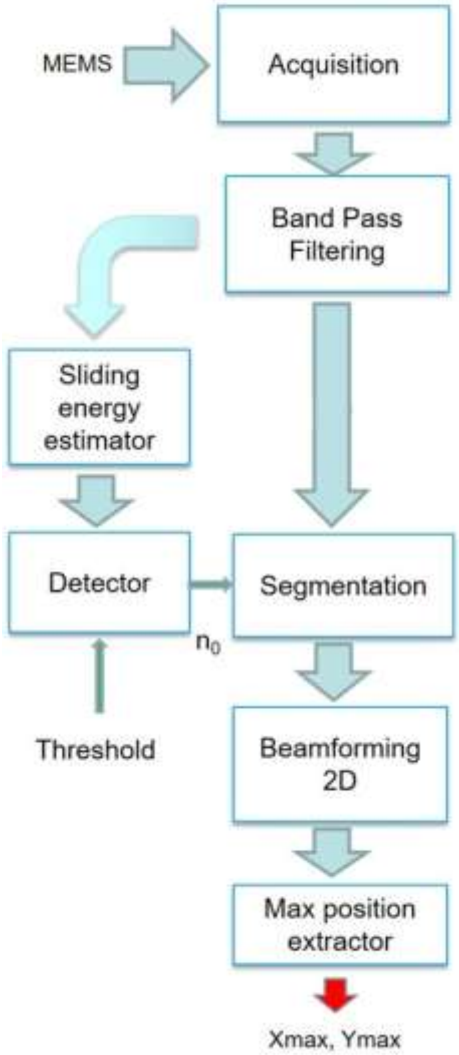

Figure 5. Processing algorithm.

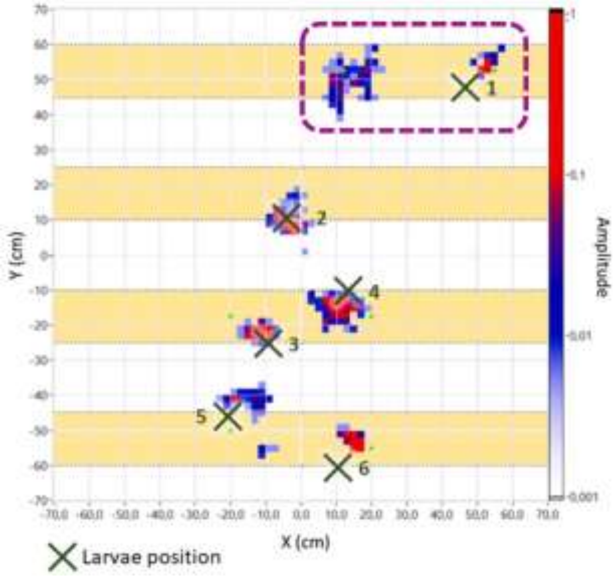

Figure 6. 2D histogram with estimated larvae positions from acoustic images.

Figure 7. Knot altering larvae localization.

Sounds produced by larvae has complex propagation mechanisms, because several reasons:

- Wood is not a homogeneous medium.
- Larvae produce internal galleries, so that the acoustic signal is generated at one point and then comes out to the surface of the beam through another point.
- There are knots and cracks in the wooden beams that can alter the point where the acoustic signal comes out (Fig. 7).

5. CONCLUSIONS

A non-contact low-cost acoustic system, based on a low-cost MEMS microphone array, has been developed for the detection and localization of multiple larvae inside wooden structures.

The work shows that anomalies in the wood, as cracks and knots, can distort the point where the acoustic signal generated by the larvae comes out of the wood. This results in failures in larvae localization.

In order to solve this problem, the authors of the article are working on trying to discriminate between real *Hylotrupes bajulus L.* larvae detections and those due to anomalies in the wood, mainly knots, using Machine Learning and Deep Learning techniques.

6. ACKNOWLEDGMENTS

This research was funded by the Junta de Castilla y León, co-financed by the European Union through the European Regional Development Fund (FEDER) (ref. VA228P20).

7. REFERENCES

[1] E.A.J. Duffy: *A Monograph of the Immature Stages of African Timber Beetles (Cerambycidae)*. London: British Museum (National History); 1957.

[2] E. Vives: *Fauna Iberica, Coleoptera: Cerambycidae*. Vol. 12. Madrid: Museo Nacional de Ciencias Naturales, 2000.

[3] M. Pallaske: "Measurement and Analysis of the Activity of Larvae of the House Longhorn Beetle Hylotrupes bajulus (L.) in Wood and in an Artificial Diet with the Aid of Modern Electronics," *Material Und Organismen*, vol 21, no. 1, pp. 63–79, 1986.

[4] R.J. Pence, S.J. Magasin, and R.G. Nordberg: "Detecting Wood-Boring Insects Electronic Device Developed as Aid in Locating Insects Destructive to Timber and Wood Products", *California Agriculture*, 1954.

[5] Y. Fujii, M. Noguchi, Y. Imamura, and M. Tokoro: "Detection of Termite Attack in Wood Using Acoustic Emissions," *in Proc. of the IRG Annual Meeting*. (Lappeenranta, Finland), 1989.

[6] M. Nowakowska, A. Krajewski, P. Witomsk, P. Bobinski: "Thermic Limitation of AE Detection Method of Old House Borer Larvae (Hylotrupes bajulus L.) in Wooden Structures," *Construction and Building Materials*, vol. 136, no. April, pp. 446–9, 2017.

[7] P. Bilski, P. Bobinski, A. Krajewski, P. Witomski: "Detection of Wood Boring Insects' Larvae Based on the Acoustic Signal Analysis and the Artificial Intelligence Algorithm," *Archives of Acoustics*, vol. 42, no. 1, pp. 61–70, 2016.

[8] I. Potamitis, I. Rigakis, N.A. Tatlas and S. Potirakis: "In-Vivo Vibroacoustic Surveillance of Trees in the Context of the IoT," *Sensors*, vol. 19, no. 6, 1366, pp.1-14, 2019

[9] Knowles: "SPH0641LU4H-1 MEMS Microphone". https://www.knowles.com/docs/default-source/model-downloads/sph0641lu4h-1-revb.pdf. Last access: March 18, 2025.

[10] T. He, Q. Pan, Y. Liu, X. Liu, D. Hu: "Near-field beamforming analysis for acoustic emission source localization," *Ultrasonics*, vol. 52, no. 5, pp. 587–92, 2012.

[11] National Instruments: "SbRIO-9607 Platform." https://www.ni.com/docs/en-US/bundle/sbrio-9607-feature/page/overview.html, Last accessed: March 14, 2025.