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RECORDING AND ANALYZING INFRASOUNDS TO MONITOR HUMAN ACTIVITIES IN BUILDINGS

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ABSTRACT

Infrasound waves originate from multiple sources, whether anthropogenic (explosion) or natural (earthquake, volcano, storm, *etc.*). They are generally used in atmospheric physics and to monitor nuclear weapons. People familiar with infrasound measurement also know that human presence and activities in buildings (moving, passing through a door, opening a window, use of machines, *etc.*) produce infrasounds. In the context of smart buildings, these infrasounds may be detected and analyzed to infer information. Infrasounds have the advantages of propagating over long distances and circumventing obstacles. For this reason, a few sensors are able to monitor a large area, but in counterpart recordings may be contaminated by undesired sources.

A campaign of infrasonic recordings by a MB3d sensor (a highly sensitive sensor manufactured by SeismoWave) was carried out in 2022 in several places (Orange office buildings and private homes). First it was observed that the signals were very noisy. Surrounding vibrations were measured by the sensor and had to be discarded by using an active isolation system. Moreover many competing sources of infrasound were recorded. Useful signals may be extracted by time-frequency transforms. After describing the proposed preprocessing, the paper will present examples of infrasonic signatures (doors, washing machine, controlled mechanical ventilation, *etc.*).

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1. INTRODUCTION

There are many ways to detect the presence and the type of human activity in a building. In addition to connected objects, it is possible to collect and exploit information from acoustic signals. Below the human audibility threshold are the infrasounds. Out of scientific curiosity and opportunity we decided to explore the possibilities offered by infrasounds to infer information on the building environment and usage. The objective being to enrich the environmental ambient intelligence from the collected information.

Infrasonic waves are sub-audible sound waves with frequencies below 20 Hz down to 0.003 Hz. Their sources are multiple and can be anthropogenic or natural such as earth-quakes, volcanic activity, severe weather and aurora [1–3]. Because of their low frequencies, these waves can propagate over long distances and are less attenuated by the various obstacles [4].

We work with an industrial partner, Seismo Wave based in Lannion, France, which is a manufacturer dedicated to infrasound sensors. A major concern of their laboratory measurement is to avoid infrasound noises induced by human activities inside their building. What constitutes a noise for *e.g.* monitoring nuclear weapons is actually usefull information for monitoring human activities in a building. Thus, Seismo Wave lent us a microbarometer, the MB3d, with which we collected a dataset of indoor infrasound measurements. Such a sensor is normally used outside for the monitoring and the study of the atmosphere [5, 6].

Previous work has already been conducted to measure the sound pressure level in the infrasound frequency range in our daily lives and its effects on health with less sensitive sensors [7–9]. In this study, we propose to analyze infrasound signals recorded by a high performance sensor, in the perspective of smart building applications. The objective is to carry out an exploratory work on the infrasound spectrum present in a building by testing various everyday scenarios.

Section 2 describes the characteristics of the MB3d sensor and the experimental setup. In section 3, results are presented. Finally, section 4 provides discussion and conclusion.

2. EXPERIMENTAL SETUP

2.1 MB3d sensor

Nowadays, digital versions of infrasound transducers are available. These new generations deliver digital-only data thanks to a built-in digitizer that samples and refines inner analog signal. Examples of such digital sensors include the MB3 digital microbarometer (MB3d) manufactured by Seismo Wave [1] . This sensor was designed to meet the IMS specifications for global nuclear monitoring [10]. A visual representation of the MB3d sensor is shown in Figure 1.

The sensor is equipped with a GPS antenna allowing us to precisely date our measurements. This sensor has an overall self-noise level at least 10 dB below Bowman's Low Noise Model [11, 12], that permits to effectively distinguish the signals of interest from the infrasound background noise. The sensor can deliver the output signal in pressure with a sensitivity of 20 mV/Pa or in pressure derivative with a sensitivity of 2 mV/Pa.s^{-1}.

Such a sensitive sensor has the particularity to measure also surrounding vibrations. It is therefore wise to be able to differentiate the vibration signals from the infrasound signals. The sensor has 4 inputs materialized by the cylindrical ducts on each side of the sensor (Figure 1), these can be corked so that the sensor measures only the vibratory signal. The various series of measurements can thus be carried out with the sensor corked and uncorked. Experiments were done with a single sensor so that this method was not completely satisfactory. Indeed, at a specific time either both vibrations and infrasound signals are measured or only the vibrations one. Ideally, at least two sensors would be needed, one for recording infrasounds and vibrations and the second one for vibrations only, for comparison purposes. Thus, several sensors will be used for next studies.

[1] https://seismowave.com/home/products/infrasound-sensors/

Figure 1. Recording setup. The digital MB3d sensor, placed on the anti-vibration device, is powered by an external battery.

2.2 Anti-vibration device

In order to reduce the vibration part on our measurements, an active vibration isolation system called the *Nano Series* (Accurion GmbH, Göttingen) was provided by Seismo Wave. This system measures and actively damps vibrations in six degrees of freedom and is designed to compensate vibration amplitudes up to 350 μm/s. It allows us to limit the vibration level on our measurements but we cannot completely isolate the sensor from continuous vibrations. Figure 1 illustrates the actual measuring setup.

3. RESULTS

A data acquisition campaign was carried out from January to July 2022 in order to constitute a database of infrasound recordings in office buildings and private homes. The data was measured by the MB3d sensor under the conditions presented in section 2. In the current section, some examples of infrasound signals extracted from collected infrasound landscapes are described. These examples were chosen because they were related to specific and identifiable human or mechanic activities encountered in the smart building field.

3.1 Controlled mechanical ventilation

The controlled mechanical ventilation (CMV) is a mechanical system whose objective is to renew continuously the air inside the building. The CMV used for our measurements is a single-flow CMV in an apartment with two air vents in two different rooms. In order to visualize the infrasound emission of the CMV, it was switched off at minute 17 and switched back on at minute 77. The pressure derivative signal is represented in Figure 2, both in time (upper part, a)) and in time-frequency (lower part, b)). The spectrogram is computed using the following parameters: Hanning window of 20-second length with 50% overlap and zero-padding.

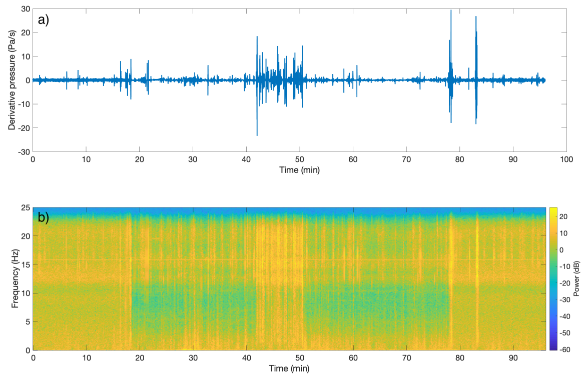


Figure 2. a) CMV time series in Pa/s. b) Spectrogram.

We can observe an increase of about 6 dB between 5 and 10 Hz when the CMV is turned on. This device emits infrasounds on a broad spectral band (in the infrasound context). The increase in energy around minute 45 is the result of vibrations generated by the movement of a person near the sensor.

3.2 Doors

Another example of an activity with significant infrasound emission is the opening and closing of doors. The opening and closing of windows has also been successfully tested. In our case, it is an entrance door of a house located a few meters from the sensor located inside the house. The closing of the door was intentionally stronger than the opening.

The pressure derivative signal is represented in Figure 3, in time (upper part, a)) and in time-frequency (lower part, c)). This time, a wavelet analysis was performed as a complementary tool to the spectrogram. The middle part (labeled b)) corresponds to the instantaneous phase of the time series.

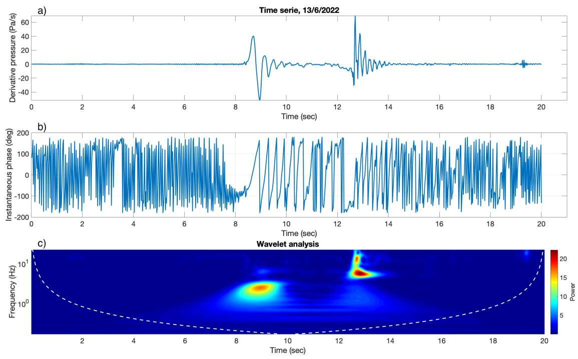
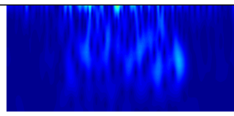
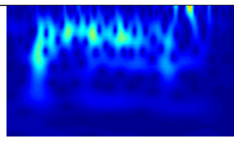
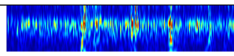
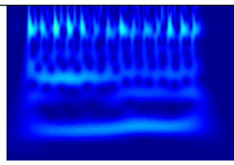


Figure 3. a) Time series of the entrance door (opening, followed by closing) in Pa/s. b) Instantaneous phase. c) Wavelet analysis. The white dotted curve represents the cone of influence of the wavelet spectrum.

The door closure is more intense than the opening, resulting in a higher amplitude of the infrasonic wave generated. We also observe the frequency shift between the opening and closing of the door. The opening of the door generates an infrasound with a frequency of about 2 Hz while the closing of the door is around 5 Hz. It should also be noticed that opening or closing the door leads to opposite behavior regarding the phase of the signal. Indeed, opening the door is translated by a noticeable positive shift in phase, whereas closing the door leads to a negative shift. Thus, in addition to the wavelet analysis which informs us of a door movement, phase analysis allows us to identify the nature of the movement (opening or closing).

Table 1. Examples of activities tested during the measurement campaign. For each activity, we gather the following information : the frequency band of the generated infrasound, the approximate distance between the sensor and the activity, the associated wavelet analysis and the duration of the wavelet analysis.

Activities	Frequency (Hz)	Distance (m)	Wavelet analysis	Duration (s)
Washing machine	[4 - 5]	6		15
Going down / climbing the stairs	[2 - 5]	4		13
Mower	3	10		240
Vacuum cleaner	[1 - 6]	3		25

3.3 Other type of activities

During the measurement campaign, many human or mechanic activities were tested. Table 1 gathers four other tested activites and their infrasonic signatures. The impacted frequency range and wavelet analysis are given for the chosen examples. The distance to the sensor and the duration of the activity is also indicated.

4. CONCLUSION AND DISCUSSION

As shown in this article, infrasounds are emitted in daily occupations and their analysis could be particularly interesting in the smart building field. More precisely, each kind of event generates its own frequency signature that could be automatically recognized thanks to a proper classifier (e.g. Machine Learning). In future works, we want to explore this possibility by using Artificial Neural Networks such as those used in [13]. In addition, localization of infrasound events will be examined by using a sensor array.

5. ACKNOWLEDGMENTS

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