A mini acoustic chamber for small-scale sound experiments

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ABSTRACT

This paper describes the design and construction of a mini acoustic chamber using low-cost materials. The primary purpose is to provide an acoustically treated environment for small-scale sound measurements and experiments using ≤ 10-inch speakers. Testing with different types of speakers showed frequency responses of < 10 dB peak-to-peak (except the "boxiness" range below 900 Hz), and the acoustic insulation (soundproofing) of the chamber is highly efficient (approximately 20 dB SPL in reduction). Therefore, it provides a significant advantage in conducting experiments requiring a small room with consistent frequency response and preventing unwanted noise and hearing damage. Additionally, using a cost-effective and compact acoustic chamber gives flexibility when characterizing a small-scale setup and sound stimuli used in experiments.

CCS CONCEPTS

• **General and reference** → Experimentation.

KEYWORDS

Mini acoustic chamber, sound insulation, sound measurement, acoustic experiment

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Figure 1: Fully constructed mini acoustic chamber. (Top left) Side view of the bottom part of the top cover. (Top right) Top view of the top cover. (Bottom left) Inside of the chamber. (Bottom right) Fully assembled chamber. The two handles are used to lift open the top cover. The round hole in the center for accessing the chamber for measurement (e.g., microphone) and observation (e.g., digital microscope)

1 INTRODUCTION

Research involving sound measurements often require a room with acoustic treatment, such as an anechoic chamber. However, professional anechoic chambers are not readily available and are costly to build. A full anechoic chamber is especially uneconomical for small-scale experiments. This is the case in our research on the effect of musical sound on biological cell cultures [12]. Our research builds on efforts to understand the mechanotransduction of cell cultures—cells grown in a controlled artificial environment in biology laboratories—induced by sound pressure waves [4]. Mechanotransduction is an essential process of the cells where mechanical signals (stimuli) are transformed into biochemical signals. In nature, cells are exposed to different types of mechanical forces such as tension, compression, and shear forces [5]. Although these mechanisms are not fully understood yet, research has shown potentially beneficial effects of audible range sound, even music in some cases, on the biological processes of the cells [12].

In a recent review study [12], we documented a high variation in the methodologies employed in investigating the effects of audible sound on cell cultures. Biological cells have a complex system that changes their behaviors by responding to chemical and mechanical cues. This requires a more sensitive approach when performing experiments using mechanical stimuli [7]. Thus it is critical to control and document the experimental setup carefully, not least to allow for replication of findings. Then it is necessary to have an acoustically controlled space for measurement and characterization

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of the sound used as stimuli for experiments [8]. Additionally, many experimental studies have employed fairly loud sound (around 90 dB Sound Pressure Level (SPL)) over several hours in some cases [4]. Exposure to such high-intensity sound can result in temporary and even permanent hearing damage to the researchers. Sound dampening devices can reduce the risk of such irreversible health hazards and protect the hearing of the researchers and staff working in the lab.

Taken together, we found the need to develop our own movable and acoustically treated "room" (Figure 1). This paper presents the design and construction of a custom-built mini acoustic chamber. We call it "acoustic," since the aim has not been to make an anechoic chamber. An anechoic chamber is designed to mimic an infinitely large room where there is no reflection of sound, minimal or no external noise entering the chamber, and where the sound generated inside does not escape the chamber [8]. Several studies have aimed at developing small [1, 2, 9, 13–15] and economic anechoic chambers [8, 10]. More recently, Jameeu et al. developed a mini anechoic chamber for antenna (electromagnetic) measurement [11]. We have been inspired by these approaches when constructing our mini acoustic chamber using materials that can be purchased at local stores.

Our intention is to pave the way for a controlled experiment environment that provides a relatively "flat" and consistent frequency response and controlled noise and loudness level. We hope this can promote controlled small-scale acoustic measurements and experiments. Our target application is sound studies on cell cultures, but the chamber could also be used for other applications. This paper illustrates the design, construction, and characterization of such a mini acoustic chamber.

2 CHAMBER DESIGN

2.1 General consideration

The shape of the chamber was one of the critical factors when we embarked on designing the chamber. After searching through relevant literature, we found that a rectangular-shaped chamber is the most practical to work with [16], although the chamber will be prone to standing waves in a higher frequency range due to its small size. Compared to more complex shapes, a rectangular shape is simpler to design, construct, and easier to use. Several other factors were considered, including chamber dimensions and net volume concerning the size and volume of test objects, absorption material types, and room modes. In the following sections, we will discuss chamber dimensions, volume, and materials used to construct the chamber.

2.2 Dimensions

The dimensions used to construct the chamber are based on the size of the test objects with respect to the ISO 3745 [6], which in our case is a standard 60 mm cell culture dish. The dimensions used for the chamber are listed in Table 1. The values were calculated according to the ISO 3745 standard [6] to provide enough horizontal space for working with the test object.

Table 1: The dimensions of the chamber

Side	Outer (cm)	Ratio	Inner (cm)	Ratio
Length (l)	33.10	1.27	23.40	1.42
Width (w)	28.80	1.10	19.10	1.16
Height (h)	26.10	1.00	16.40	1.00

Table 2: The thickness and costs (in Euro) of the materials

Material	Thickness (cm)	Cost (€/m^2)
Plywood (red temp)	2.20	33.50
Rockwool	2.00	5.80
Felt	0.50	8.20
Acoustic foam	5.00	60.50
Miscellaneous	-	60.00
Total	9.70	168.00

2.3 Volume

ISO 3745 suggests that, for a full anechoic chamber, the volume (V) of the test subject for measurement should be 5% of the net volume of the chamber: $V_{specimen} \leq 0.05 \cdot V_{chamber}$ [6]. The gross volume of our chamber is: $V_{gross} = 33.1 \cdot 28.8 \cdot 26.1 = 24,880.6\, cm^3$ and the total thickness of one side of the wall materials is 9.7 cm. The net volume of the chamber is then: $V_{net} = 23.4 \cdot 19.1 \cdot 16.4 = 7,330\, cm^3$.

A typical volume for a 60 mm cell culture dish is (radius=3 cm, height=1.6 cm): $V_{60mm} = \pi r^2 \cdot h = 45.2\, cm^3$. Therefore, the volume requirement of the ISO 3745 is then satisfied since: $V_{60mm} < 0.05 \cdot V_{net}$.

2.4 Materials

The aim was to construct a cost-effective chamber using readily available materials (Table 2). We used a computerized numerical control (CNC) milling machine[1] to cut the material to size in a public maker space. The fully constructed chamber and its parts can be seen in Figure 1.

3 CHARACTERIZATION OF THE CHAMBER

For the characterization of the chamber, we used a setup (Figure 2) with an omnidirectional calibration microphone having a flat frequency response (Earthworks M50) connected to a sound card (Behringer UMC404) and free software (Room EQ Wizard (REW) version 5.19) on a laptop. The location and types of speakers were varied for comparison.

3.1 Sweep used for the measurement

We used REW on a laptop to generate the logarithmic sine sweep from 0 to 22 kHz (from DC to 10 Hz was a linear sweep). The total time of the sweep, including silences at the beginning and end of the sweep, was approximately 6 seconds. This was based on having 256k samples in a sweep.

[1] ShopBot CNC milling machine: https://wiki.bitraf.no/wiki/Fresing

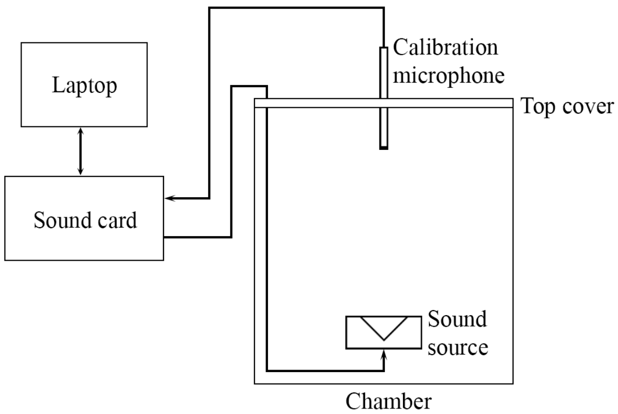

Figure 2: Flowchart of the measurement setup.

3.2 Measurement

We used three different types of speakers (sound sources) for comparison:

- Sound source 1: A surface transducer (ST) coupled with a 60mm cell culture dish
- Sound source 2: A two-way 10-inch coaxial speaker
- Sound source 3: An active two-way studio speaker (Genelec 8020b), used for sound insulation test placed outside the chamber

First, we characterized sound sources 1 and 2 using the types of speakers of suitable size for the chamber. Then we characterized the chamber using the sine sweep. We tested sound insulation efficiency using broadband noise for about 20 seconds through sound sources 2 and 3, which were kept outside the chamber. The measurement was divided into two sections and taken in the following order:

- Measurement 1: Sine sweep in the chamber with or without the chamber cover
- Measurement 2: Broadband noise with a microphone in or outside of the chamber

3.3 The modes of the chamber

A distribution of modes is crucial to avoid any heavy concentration of energy. As mentioned above, an ideal chamber would have an irregular shape but would be difficult to build. The Bolt-area indicates an accumulation of good room ratios [3] and has been tested using the inner dimensions and the ratio of the chamber on Amcoustics.com. The chamber is within the so-called "safe zone," and the modes are likely to be distributed more evenly than if the proportion of the chamber fell outside of the "safe zone."

In a rectangular-shaped space, a room mode is defined by:

$$f = \frac{v}{2}\sqrt{\left(\frac{l}{x}\right)^2 + \left(\frac{m}{y}\right)^2 + \left(\frac{n}{z}\right)^2} \quad (1)$$

where l, m, n are positive integers that cannot be all 0. As a reference, the first five modes of the chamber can be seen in Table 3.

Table 3: The first five modes of the chamber.

Mode number	Frequency (Hz)	*l-m-n*
1	732.91	1-0-0
2	897.91	0-1-0
3	1045.73	0-0-1
4	1159.05	1-1-0
5	1276.99	1-0-1

4 RESULTS

Figure 3 summarizes the frequency responses from the experiment. In measurement 1, we observed the distinctive frequency responses of the two systems. For sound source 1, the high positive peak around 8 kHz (λ ~43 mm) is speculated to be a resonant frequency created from the coupling between the transducer (Ø = 30 mm) and the coupled dish (Ø = 60 mm). For sound source 2, the negative peak below the 2 kHz area fits the specification description from the manufacturer of the speaker.[2] The difference between the measurements with or without the chamber cover is the boosts in the frequencies below about 100 Hz when the cover is closed, effectively making our chamber "behave" like a pressure chamber.

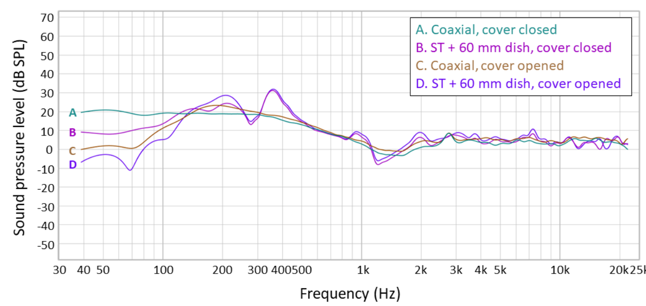

Figure 3: Acoustic chamber frequency response. The response is relatively flat above 1 kHz.

For the sound insulation effectiveness of the chamber, we compared the measured dB SPL level (measurement 2) using the room noise level as our reference. There was about a 20 dB SPL reduction when the broadband noise (sound source placed outside the chamber) was measured from inside of the chamber than when it was measured from outside of the chamber (Figure 4). We suspect the reduction could have been larger since the measurement outside the chamber was very similar to the room noise level.

An interesting and perhaps predictable finding is the frequency boosts in the range between 100 and 900 Hz in the frequency response of the chamber, as can be seen in Figure 3. The chamber's "boxiness" seems inevitable in such a confined space. The chamber frequency response's higher range (from 1 to 20 kHz) is generally constant (±4 dB SPL), and the variation is not as extreme as the "boxiness" frequency range.

[2]More information can be found on the project web page: www.uio.no/ritmo/english/research/interaction-robotics/sound-box/index.html

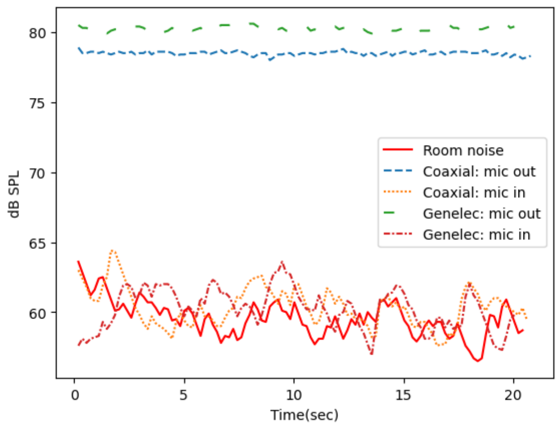

Figure 4: dB SPL measurement of broadband noise comparison. The speakers were kept outside the chamber and measured with the microphone outside and inside the chamber.

5 DISCUSSION AND CONCLUSION

The main aim of this paper was to produce an acoustically controlled space for small-scale acoustic measurements and experiments. We have described the design of a mini acoustic chamber that can be constructed at a minimal cost using a simple design for research and small-scale sound measurement or experiment purposes.

The chamber was characterized in terms of its frequency response and sound insulation efficiency using various sound sources. After the characterization, it became clear that the "boxiness" of such a small chamber is inevitable, and it should be taken into account when performing experiments. Despite the downfall, we succeeded in reaching our goals. Firstly, the frequency response of the chamber showed a fluctuation of less than 10 dB SPL and stayed approximately flat from 1 kHz up to about 20 kHz. Secondly, the sound insulation test of the chamber showed a significant reduction (approximately 20 dB SPL).

These are positive results for our purpose (acoustic experiments on biological cell cultures) and possibly for other small-scale experiments and measurements, for example, small antenna measurements. We hope that such a simple and small acoustic space, like our mini acoustic chamber, will provide a more controlled and accessible space for small-scale experiments.

The aim now is to use the chamber in experimental studies of cell cultures in laboratories to reveal any shortcomings of the constructed chamber. Knowledge from the practical work and adjustments to the ratios and dimensions of the chamber could be used to construct another chamber that is more safely within the Bolt-area. It would also be interesting to characterize the chamber without the absorption materials, which could give a better understanding of how the materials are performing.

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