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A Multi-Channel Vibrotactile Speaker System for a More Equally Shared Musical Experience Between Deaf and Hearing Individuals

Authors

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Abstract

Tactile modality is an intriguing sensory avenue, particularly explored as a way for deaf individuals to experience music through technology. However, most audio-tactile systems developed in research or commercially available today focus on converting existing music into vibrations. Consequently, vibrotactile music composition (creating music specifically for the body through vibrations) remains largely underexplored. The author argues that this discipline could encourage more equal interaction and sharing of the musical experience between deaf and hearing individuals and in this paper, a multi-channel, vibrotactile speaker designed to achieve this goal is presented. It reproduces analog audio signals from a standard electro-acoustic chain (source, audio interface, amplifier) and can be constructed for a cost of approximately 200 to 600 €, depending on access to a large-format 3D printer.

Metadata Overview

Main design files: https://doi.org/10.5281/zenodo.13919685
Target group: researchers and performing arts professionals wishing to set up an experimental project
Skills required: Large-format 3D printing - intermediate; hand tool use - easy (mechanical assembly); electrical soldering - intermediate; CNC laser cutting and engraving - easy; software - intermediate (audio routing; DAW use).
Replication: The system is currently utilized for the author's scientific research in connection with their PhD thesis, as well as for prototyping within an entrepreneurial project.
See section "Build Details" for more detail.

Keywords

Vibrotactile; accessibility; deaf; music; multi-channel speaker; haptic

(1) Overview

Introduction

Driven by international political guidelines supporting inclusion and the right of people with disabilities to fully participate in cultural activities [1], the past decade has seen a surge in research focused on creating shared musical experiences that are more inclusive for deaf and hard-of-hearing individuals. In France, several collaborative projects between industry professionals and the academic sector have fostered spaces for joint reflection and experimentation. Notable examples include cultural mediation initiatives such as TOTEM [2] and EGAL [3], as well as various scientific events [4,5]. Additionally, many concert venues and music festivals now incorporate audio-tactile devices, like wearable tactile bass systems, as part of their accessibility efforts. By providing these devices to deaf audiences, the goal is to offer access to the concert experience by compensating for hearing loss through alternative sensory channels [6].

At the same time, the use of tactile modalities to convey musical information, aimed at enhancing the musical experience for deaf individuals, has been a consistent focus of research in Human-Computer Interaction (HCI) for many years [7-10]. Studies have shown that this sensory approach offers unique benefits, allowing many deaf individuals to engage with music through “corpaurality”—the act of listening through the body [11]. As a result, this form of bodily listening has become recognized as a fundamental aspect of the deaf musical experience [12].

One of the most common methods for making music more accessible to deaf individuals is through Sensory Substitution, specifically Audio-Tactile Substitution (ATS). However, this approach often limits the listening experience for these individuals, reducing many of the dimensions integral to musical performance [13]. By merely adapting existing environments without challenging dominant norms—particularly those based on hearing—this method fails to fully promote the social participation of deaf individuals in all aspects of music, including composition. Despite this, the field of musical composition using tactile modalities has been explored in a few studies [14-16] and has recently emerged as a practice known as “Vibrotactile Music Composition” (VMC) [7].

However, efforts to establish a guiding principle for composing with vibrations and for the tactile modality remain limited to only a few studies, with no consensus emerging among them. To address this gap, our PhD thesis proposes a new compositional framework for vibrotactile music, called “trajectorial composition” [17,18]. Drawing inspiration from research on Mediated Social Touch (MST) [19] and spatialization techniques in electroacoustic music [20], the trajectorial composition principle leverages tactile motion illusions (the “phi phenomenon”) to create “vibrotactile trajectories”. These trajectories can be organized in both time and space, much like notes in traditional Western music notation system.

Since none of the commercially available audio-tactile technologies, nor those proposed in academic literature, were adequate for reproducing vibrotactile music based on our compositional principle, we developed our own open-source hardware solution for research purposes. This paper introduces a multi-channel vibrotactile speaker designed to offer both deaf and hearing individuals a more equally shared musical experience. It also provides detailed instructions on how to replicate this solution for future research or applications beyond the scientific community.

Overall Implementation and design

Enclosure

The enclosure consists of two identical parts (448 x 320 x 56 mm) that can be positioned opposite each other to form the front and back sides of the speaker (**Figure 1**). The overall shape is ellipsoidal with flat surfaces both inside and out, making it easier to assemble the exciters internally (see the next section: “Vibrating plate and actuators”). The enclosure is produced using additive manufacturing, specifically Fused Filament Fabrication (FFF). For this model, we used a layer height of 200 µm and

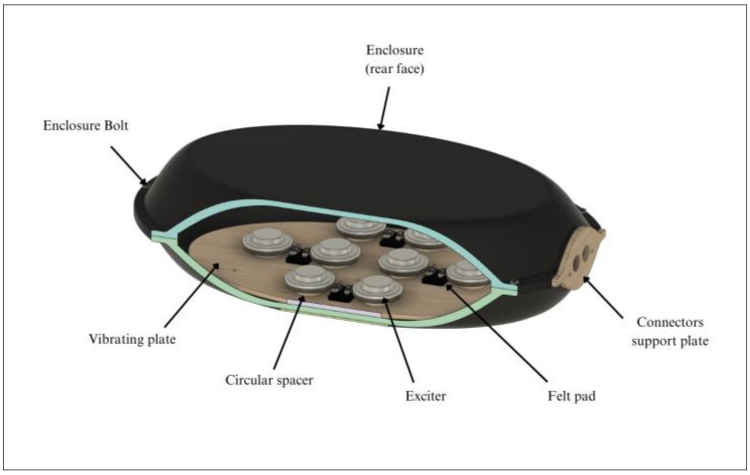

Figure 1: Cross-section of the speaker CAD drawing.

an infill density of 20% (grid pattern). The material chosen for the enclosure is polylactic acid (PLA). The two parts of the enclosure are bolted together using seven drill holes along the assembly plane, which is a 10 mm wide border forming the outer contour of each part (**Figure 2**). Both parts are 6 mm thick. M3 threaded screws, 16 mm in length, are used for assembly.

Additionally, two drill holes at the base of the enclosure allow for the installation of the electrical connectors for the audio signal input. These holes have a diameter of 16 mm. Two more drill holes are used to attach a 5 mm thick laser-cut wooden plate, referred to as the “support plate”, which is shaped to match the base of the enclosure (**Figure 3**).

A 5 mm-thick sheet of felt is adhesively bonded to the front face of the enclosure to improve user comfort and conceal the heads of the assembly screws.

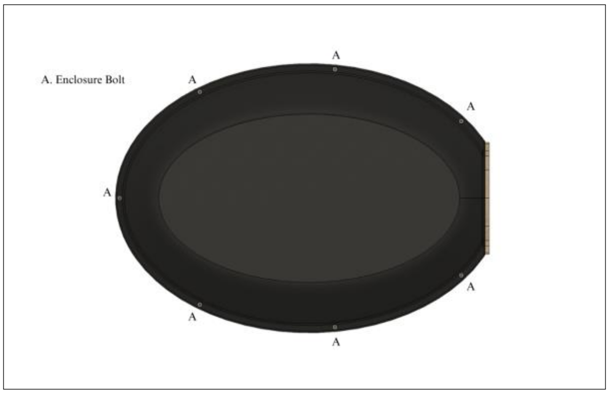

Figure 2: Front view of the speaker CAD drawing.

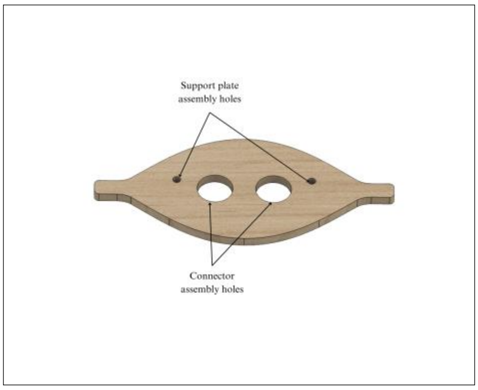

Figure 3: Overview of the connector support plate CAD drawing.

Vibrating plate and actuators

The actuators used are electrodynamic voice coil transducers (Dayton Audio DAEX25CT-4), commonly referred to as “exciters”. These actuators offer several advantages: their technical specifications—power, impedance, frequency response, size, and mass—are ideal for the intended application. They are also affordable, widely available, and have a long commercial lifespan. The eight exciters are arranged equidistantly in a 3 x 4 matrix (3 columns, 4 rows) on the surface of a wooden “vibrating plate”, which was laser-cut using CNC technology (**Figure 4**). The spacing between exciters along both the x and y axes is 70 mm. The vibrating plate itself matches the inner flat surface of the speaker enclosure, shaped as an ellipse measuring 365 x 200 x 5 mm.

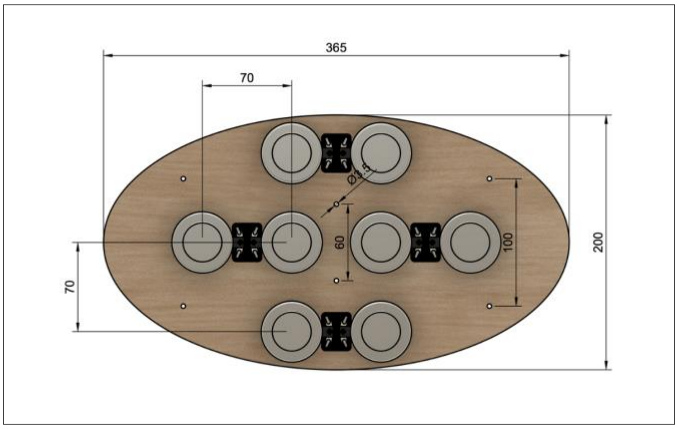

Figure 4: CAD drawing of the vibrating plate with dimensions.

To attach the exciters to the vibrating plate, each exciter's moving coil is glued to a laser-cut wooden spacer, measuring 25 mm in diameter and 5 mm thick. These spacers feature a central drill hole to fit a T-nut with an M4 thread. By screwing in from the outer front side of the enclosure, the entire assembly is securely fastened. This design also allows for easy replacement of exciters if needed. Additionally, several holes were laser-cut into the vibrating plate to enhance its connection to the inner front face of the speaker enclosure, and this assembly is similarly screwed to the outer face for added stability.

Wiring and connectors

The input connectors for the multichannel audio signals consist of two male 8-pin GX16 “aviation connectors”, mounted on the support plate. The exciters are wired to these connectors using 1.5 mm^2 cross-section cables, with solder joints protected by heat-shrink tubing for durability.

Figure 5: Removable speaker audio cable with view of the two female GX16 8-pin connectors.

The cable transmitting the audio signals to the speaker contains eight pairs of the same type of cable, bundled together in an extensible nylon braided sheath (**Figure 5**). One end features two female GX16 connectors for easy attachment to the speaker. The solder joints and exposed cable sections are also shielded with heat-shrink tubing. The opposite end connects to the signal amplification system, and you may need to adjust the wiring depending on the output connectors of the amplifiers used.

(2) Quality Control

Safety

Electric shock: The speaker should never be used when disassembled or open. Make sure all soldered joints and exposed cable sections are properly insulated with heat-shrink tubing. Additionally, avoid using the speaker in extreme temperatures or damp conditions, and keep it away from heat sources and liquids to ensure safe operation.

Burning and toxicity risks: When using a soldering iron or heat gun during assembly, be cautious, as these tools can cause burns or fires. Additionally, always use a fume extractor and filtration system while soldering to avoid inhaling harmful fumes and particles. Safety precautions are essential to prevent accidents and ensure a healthy working environment.

Safety precaution with CNC machines (3D printer; laser): Using 3D printers and CNC lasers carries significant risks that can affect both health and the environment. It's crucial to have a clear understanding of these machines before operating them. Ensure you're properly trained or supervised, such as in a fablab setting, to use these tools safely and responsibly. Proper knowledge and precautions are key to minimizing hazards.

Crushing and rotating tool injuries: Assembling the speaker components requires hand tools, such as a hammer, and a rotary tool for drilling. Always wear appropriate safety gear, such as gloves and safety goggles, to protect yourself from potential injuries like crushing or debris-related accidents during the assembly process. Safety precautions are essential for a secure working environment.

Vibration-related health hazards: Prolonged or intense vibrations can pose health risks. Avoid using the speaker or exposing individuals to vibrations if they have a heart condition (e.g., wearing a pacemaker), musculoskeletal disorders, epilepsy, recent surgeries, or are pregnant or may be pregnant. If you're unsure, consult a healthcare professional to ensure the device is safe for use. Safety and health should always be prioritized when operating equipment with strong vibrations.

General testing

The speaker testing process consists of two stages. The first stage involves verifying the hardware-software mapping between the physical channels (the exciters) and the virtual channels in the control software (DAW). To check this, send a signal to each channel and visually observe, with the speaker enclosure open, whether the corresponding exciter vibrates in response. If the vibrations do not match the signal sent, you'll need to adjust the virtual channel positions in the spatialization plugin to correct the mapping.

The second step is to ensure that parasitic vibrations are not affecting signal reproduction. These unwanted vibrations can stem from three main causes: (1) signal clipping due to exceeding the peak level (> 0 dBFS); (2) excessive amplification power; (3) mechanical components transmitting vibrations to the speaker enclosure (e.g., cables or exciter terminals). We recommend a simple testing procedure using a sine wave generator, with peak levels set at 0 dBFS, to test various frequencies between 20 and 250 Hz. If mechanical vibrations are detected, identify the specific material causing the issue and apply an appropriate solution to dampen or neutralize the vibrations (e.g., felt pads, cable ties, or foam sheathing).

(3) Application

Use case(s)

The device was employed in our PhD thesis [17], where the study aimed to evaluate the recognition of emotions conveyed by vibrotactile music sequences, composed following the principles of *trajectorial composition*, among both deaf and hearing participants. Additionally, the system was showcased at a scientific workshop [21], and numerous tests have been conducted over recent years (**Figure 6**) to gather feedback for future improvements. Some of these responses, written in French, are detailed in our PhD thesis.

The system is versatile and can be applied in various fields and contexts, including scientific and artistic research on vibrotactile music, shared musical experiences between deaf and hearing individuals, emotional perception through tactile stimuli, and Mediated Social Touch. Additionally, several testers

Figure 6: *Overview of the standard speaker system setup.*

have proposed that the device could be used in well-being contexts, such as a vibratory massage tool. It also holds potential for use in artistic installations.

(4) Build Details

Availability of materials and methods

The exciters are available through Dayton Audio brand distributors. All electrical and assembly components (GX16 connectors, cables, screws, and bolts) can be sourced from general online retailers like Amazon. The wood for the vibrating plate, circular spacers, connector support plate (e.g., basic plywood panel), and felt elements can be found at a local DIY store.

Additive manufacturing may be the most challenging part of the process. The enclosure was printed using a BCN3D Epsilon W50 large-format 3D printer (printing volume: 420 x 300 x 400 mm). If you don't have access to a similar machine, consider reaching out to a service provider that offers on-demand 3D printing (the cost can range from 150 to 400 € for both parts). The material used for printing is standard PLA. The wooden parts were machined using a 30W CO2 laser (Epilog Mini 24) at a local fab lab. The STL file for the enclosure, as well as the files for laser cutting and engraving the wooden parts (available in SVG and PDF formats), can be downloaded.

The following hand tools are needed for assembly: a hammer (for the T-nuts), a set of hex keys and screwdrivers (for the bolts), an electric soldering iron, a heat gun (for the heat-shrink tubing), fine-grain sandpaper (for finishing the wooden parts), a drill with a conical step bit (for drilling connector holes in the speaker base), and strong liquid glue (for attaching the exciters and spacers).

There are several construction tips that can simplify the speaker assembly process. Since the drill holes aren't pre-made in the printed speaker enclosure, it's best to use the wooden parts (vibrating plate, circular spacers, and connector support plate) as drilling templates. We recommend using a precision rotary tool, such as a Dremel-type multifunctional tool, or a small drill press. Set the tool to a moderate speed to avoid melting the PLA material of the enclosure. If possible, use locknuts for all assembly bolts to prevent them from loosening due to vibrations. Be careful not to overtighten the bolts, as excessive torque could deform or crack the enclosure. A standard Bill of Materials (BOM) is available for download.

Ease of build / Design decision

The device was designed as an experimental tool for scientific research into musical emotions experienced through vibrations. As such, it had to meet several specific requirements: the ability to reproduce tactile motion illusions, portability by a single person, quick setup and teardown, low-cost manufacturing, and a moderate weight to prevent fatigue during use. The device also features universal ergonomics, ensuring accessibility regardless of the user's gender or physical condition. Additionally, the decision to stimulate the front of the body, rather than the back, was inspired by the common practice among many deaf individuals who wear vibrating vests on the front during live music performances.

Operating software and hardware peripherals

The speaker is designed to integrate with a standard electro-acoustic setup, and there are various ways to connect the system to a computer. In our configuration, we used two 4-channel amplifiers (Behringer EPQ304 Europower) mounted in a 19" rack, along with a multi-channel USB audio interface (ESI Gigaport eX). Most DAW (Digital Audio Workstation) software can generate signals and control vibrotactile trajectories. We selected REAPER (by Cockos) for its strong multichannel support, free trial access, and a wide range of built-in audio plug-ins. Two plug-ins that can control vibration spatialization are ReaSurround and ReaSurroundPan. We have provided a preset file that sets up the virtual channel positions for ReaSurroundPan.

Hardware documentation and files location:

Archive for hardware documentation and build files (required)
Note: We require the inclusion of modifiable design files as well as detailed documentation of the design rationale of the hardware with assembly instructions. This will be assessed as part of the journal peer-review process.
Step-by-step build instructions must be available online in a repository or submitted as supplementary material.

Name: Temporary repository (GitHub): albanbriceno-ULille
[https://github.com/albanbricenoULILLE/albanbriceno-ULILLE.git]
Persistent identifier: https://doi.org/10.5281/zenodo.13919685
Publisher: Alban Briceno (author)
Date published: 2024-08-10

(5) Discussion

Conclusions

The device presented in this paper is a multi-channel vibrotactile speaker designed to offer both deaf and hearing individuals a more equally shared musical experience. It consists of eight exciters (electrodynamic audio moving voice-coil actuators), each representing an independent channel, arranged equidistantly on a CNC laser-cut wooden plate. The unit is housed in a symmetrical, two-part 3D-printed enclosure that is bolted together. The speaker operates in a passive configuration, capable of reproducing analog audio signals from a standard electro-acoustic chain, which includes a source (computer), a Digital-to-Analog Converter (DAC) audio interface, and an amplifier. The total cost to build the device ranges from approximately 200 to 600 €, depending on access to a large-format 3D printer. By offering this device as open hardware, we aim to promote the adoption of this technology, ensuring greater accessibility and enabling more inclusive interactions around music, regardless of hearing ability. This openness also encourages the reuse of the technology for scientific and artistic research, as well as for non-academic projects and initiatives.

Future Work

After extensive system testing, we gathered substantial feedback from deaf, hard-of-hearing, and hearing individuals. This feedback identified several areas for improvement. As a result, a new version of the system is now in development. Key features being addressed include the ability to use multiple speakers simultaneously, a more compact design, and the option to carry the loudspeaker hands-free, such as with suspenders or straps.

Paper author contributions (CRediT)

Design, assembly, testing, use cases contribution, documentation and paper writing, Alban Briceno.

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Competing interests

The author have no competing interests to declare.

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(6) Licenses

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