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The TOTEM project: Recent developments on a device that transforms live music into vibration

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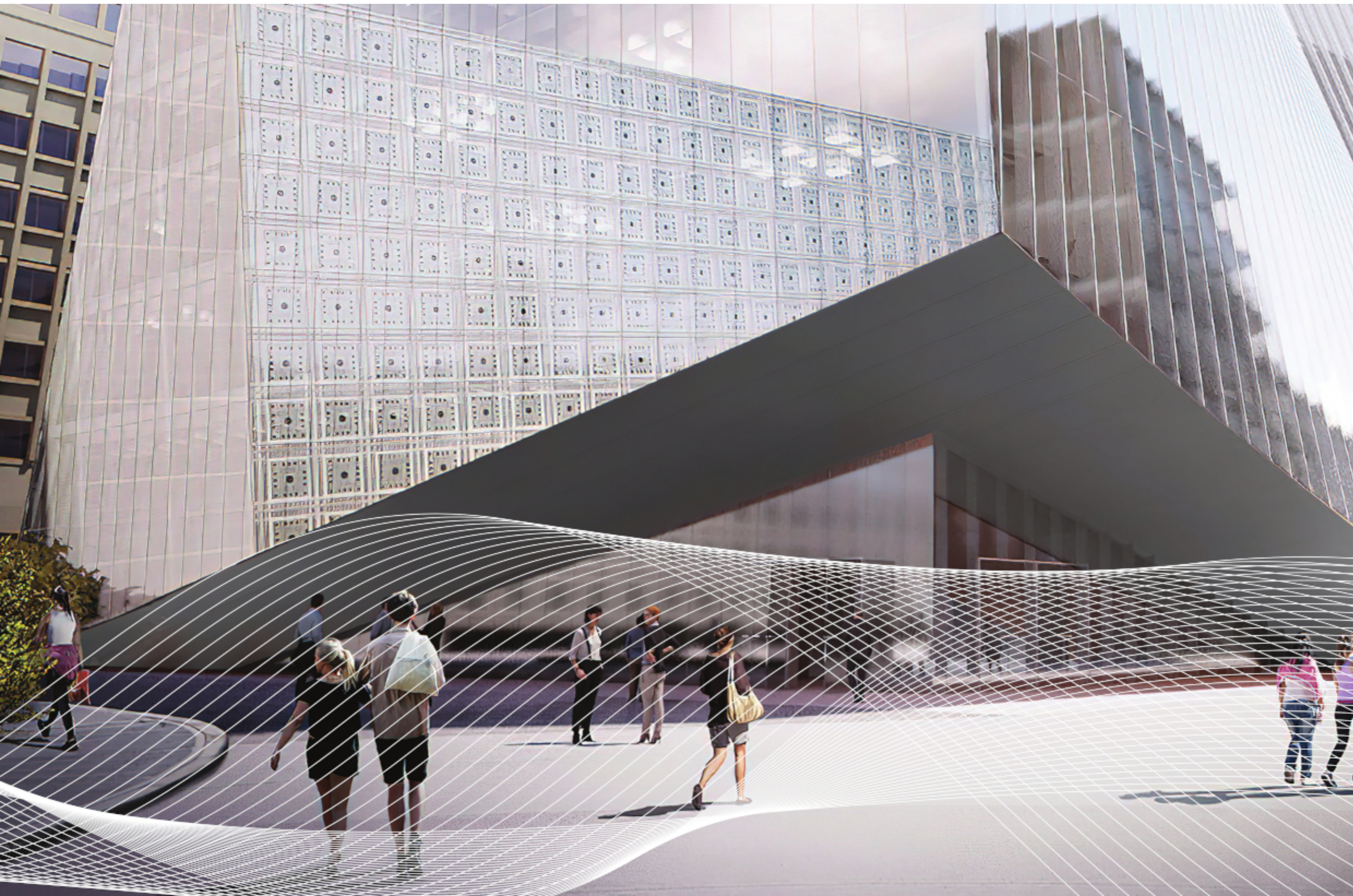

The TOTEM (TOuch ThE Music) project brings together various actors (research laboratory, live music venue, association and band of Deaf musicians), in order to work on solutions towards the inclusion of the d/Deaf in live music concerts. Among the diversity of solutions implemented in the project (e.g. communication toward the Deaf community, sign singing, ...), we will focus more here on the Action Research consisting in the design and realization of portable and autonomous devices that transform the music being played on stage into vibration displayed onto miniature actuators held by people in the audience, in real time. The scientific and technical locks are numerous, from the creation of an algorithm that is adapted to the characteristics of both our auditory and tactile sensory systems, to real-time computation, ergonomy, ... The aim of this article is to present the latest updates on this project, e.g. the redesign of the software architecture (centralization of computations allowing for improved portability of the device and leveraging more flexible broadcast possibilities, transmission of raw sound and processed vibratory signals over WiFi enhancing the versatility of the system by distributing more input and output signals to more users, ...).

1 Introduction

Outside of the Deaf community, very little is known about the relationship of d/Deaf [1] people to music. Attending a music concert is a popular social practice (76% of French people claim music has an important place in their life, and 47% attended at least one concert over the last 12 months [1])... for non-deaf people ! Concerts remain audio-centered events that exclude the d/Deaf, although 71% of deaf people say music has an important place in their life, and 70% of them say they listen to music [2].

Thirty-eight percent of deaf people say they have a musical practice [2], and the musical practices of the d/Deaf are often based on the perception of the vibration produced by low-frequency sounds : 65% of the deaf report they feel the music with their body [2]. In particular, amplified music at high levels during live performances allows the deaf to perceive musical information such as rhythm and bass-frequency content, via the haptic modality. However, physical (only the lower audio frequencies produce high enough vibration levels) and physiological (the mechanoreceptors under the skin are sensitive to stimulations within the 10–1000 Hz range [3]) limitations imply that the rest of the audio spectrum is not perceived through the haptic sense, including melody, timbre, rhythmic superstructure...

Focusing on the technological side of the problem, it can be found that quite a number of attempts at transforming sound into vibratory stimulation can be found in the literature, see e.g. [4, 5] for reviews. Available and well-known technologies like e.g. the *Subpac* [2] (a backpack with embedded actuators) or Woojer [3] (available as a backpack or a belt with embedded actuators) are originally designed for virtual reality and video games, but can be efficiently used with (live) audio signals as inputs, enhancing the bass-frequency content and providing a feeling of immersion. However, only the low frequencies of the audio signal are kept and directly fed into the actuators, leaving aside the medium and high frequencies. Other early approaches consist in compressing the audio frequency range to the vibrotactile frequency range, see e.g. [6]. Our differential thresholds in frequency being much larger in the vibrotactile modality [7] than in the auditory modality, the drawback of such frequency-range compression methods is that, by mapping a wide frequency range into a much narrower one, they decrease our capacities to discriminate frequencies in the vibrotactile domain. Although promising, approaches that take into account both the whole audio range and the characteristics of our vibrotactile perception, seem to be rarer and less known to the general public. Let us mention [8] that take advantage of the very wide spatial extension of our physiological sensors (all over the skin) in displaying different audio frequency bands onto different body areas, or [9] that use a symbolic rather than analog approach by exciting different body areas with simple eccentric-mass motors.

Our project aims at contributing to the inclusion of the d/Deaf to the music concert as a social and cultural event, among others by using innovative technological means of converting the information contained in the musical sound signal into meaningful vibratory stimulation. The hypothesis is that giving a vibrotactile representation of the musical sound that covers the whole audio range and complies with the specificities of our vibrotactile perception will strongly enhance the d/Deaf's experience as full members of the audience. The context that is chosen for this project is the live music concert, thus implying strong real-time constraints. Section 2 presents the TOTEM project with its past and current implementations, section 3 relates the latest updates on the project, and section 4 gives further directions for the ongoing project.

1. In this article, we write "deaf" with a lowercase 'd' to refer to an individual having a hearing impairment (biomedical and audiometric point of view) ; and "Deaf" with an uppercase 'D' to refer to an individual belonging or claiming to belong to a specific group of individuals sharing a common identity and culture as deaf people (anthropological and cultural point of view).

2. https://subpac.com/, retrieved March 19, 2025

3. https://www.woojer.com/, retrieved March 19, 2025

2 The TOTEM project

2.1 Past actions

A former version of the project was implemented during the 2019–2020 period. The main actions (technological solutions as well as other actions, see details in section 2.2) as well as a description of the developed devices (both hardware and software) are recounted in [11].

On the hardware side, the "user device" (still in use in the current instance of the project) consists in a box containing a *Raspberry Pi* nano-computer, a sound interface, an amplifier, and two electrodynamic, "coin type" actuators (see figure 1). We use moving-coil actuators (*Dayton Audio DAEX25CT* actuators with 10W nominal power or *Dayton Audio DAEX13CT* actuators with 3W nominal power), because of their low price and availability, as well as their ability to be driven by audio signals. Figure 2 shows a user holding an actuator in each of their hands, the box being stuffed into a textile bag for facilitating usage and mobility during the show.

On the software side, the workflow was as follows : 1) two separated audio signals were sent from the mixing desk over a wireless HF-radio transmission, 2) each user device included a HF-radio receiver connected to the inputs of the sound interface, 3) on each user device's *Raspberry Pi* an instance of `Pure Data` [4] handled the transformation of the input audio signals into vibrotactile signals, 4) the vibrotactile signals were sent to the two actuators through the sound interface's two output channels and the stereo amplifier. It is deliberately chosen to present the raw actuators not embedded in ergonomic cases or objects so that users keep having the choice of the body area they want to stimulate (we therefore were able to observe users place the actuators on their hands, forearms, neck, thighs, chin, etc. [11] so on much more diverse areas than what is constrained by other available commercial devices).

The current project inherits from (hardware) and extends (organization of the software workflow) this former iteration.

2.2 Current implementation

TOTEM is an Action Research project, implemented over the 2022–2025 period by three partners : the *Musique Pi Sourd* association (promoting Deaf culture and practice), the music venue *Aéronef*, and the acoustics laboratory at *Junia/IEMN*. The aim of the project is to design and develop solutions for the inclusion of the d/Deaf to live music events. As a purely technological solution, whatever its efficiency, will not succeed if not coupled with social actions, three complementary directions are taken in parallel :

Communication and inclusion A special communication strategy is implemented towards the d/Deaf networks and communities, in order to involve them in and invite them to our different actions (see below).

Raising awareness During our actions, and concerts in particular, efforts are made to increase our visibility (sign-singing the concerts, running a booth with explanations and demonstrations in the entrance lobby, welcoming the users to the events and guiding them to the different places of interest, introducing the topic through live testimonies from Deaf musicians, etc.) and we also promote other people with projects in the topics of music and deafness by inviting them demonstrate their approach to our audience.

4. A graphical programming language for real-time audio processing, see [10] and https://puredata.info/, retrieved March 19, 2025.

Technology This is the development of the aforementioned device that transforms sound into vibrations.

The development of the technological device is made following an iterative and inclusive approach, looping between points 1 and 2 below, interspersed by 3 occurrences of point 3 :

1. Tests and development as workshops in the laboratory, between researchers and Deaf musicians (14 workshops in total) ;
2. Real-life tests during live concerts from the *Aéronef* regular program, where d/Deaf users are specially invited (6 concerts in total) ;
3. 2-day residencies with all partners (as an extension to the lab workshops, over a longer period and still within a live music context) followed by public performances at *Aéronef* (3 occurrences in total).

3 Latest developments – WiFi routing of signals

As stereo HF-radio transmission was chosen in the previous implementation, the number of channels that can be transmitted to each user device was limited to 2. In case one wants to use other input channels, the technicians in charge of the sound desk and deployment of the devices must disconnect the two unwanted sound desk outputs from, and connect the two wanted outputs to the HF-radio transmitters, by hand. To overcome this limitation, the whole signal transmission workflow was refactored.

The modifications in the communication workflow are displayed in red in figure 1. It was decided to transmit signals to the user devices over a WiFi local network. As each device embeds a *Raspberry Pi* equipped with a WiFi card, this avoids the use of HF-radio transmitters/receivers. The version that was approved during laboratory tests and that is now under testing in concert conditions is the following : 1) N audio signals are sent over audio cables from the mixing desk to the inputs of a sound interface connected to a "central" laptop computer (the only limitation on the number N of audio signals is the number of available inputs of the sound interface), 2) an instance of `Pure Data` runs on the central computer and transforms the N audio input signals into M vibrotactile signals (each input signal can be transformed into several vibrotactile signals or just discarded, resulting in any of the following cases : $N = M$, $N > M$ or $N < M$), 3) for each user device, the operator of the central computer chooses 2 among the M vibrotactile signals and sends them over WiFi to this user device (each device can therefore receive the same 2 vibrotactile signals, or different signals), 4) each user device directly plays the 2 received channels on the actuators (no instance of `Pure Data` runs on the user devices).

Technically speaking, it is possible to transmit $M > 2$ signals to each device (even more so because their bandwidth as vibrotactile signals is very limited with respect to the bandwidth of audio signals), but we temporarily restrict to

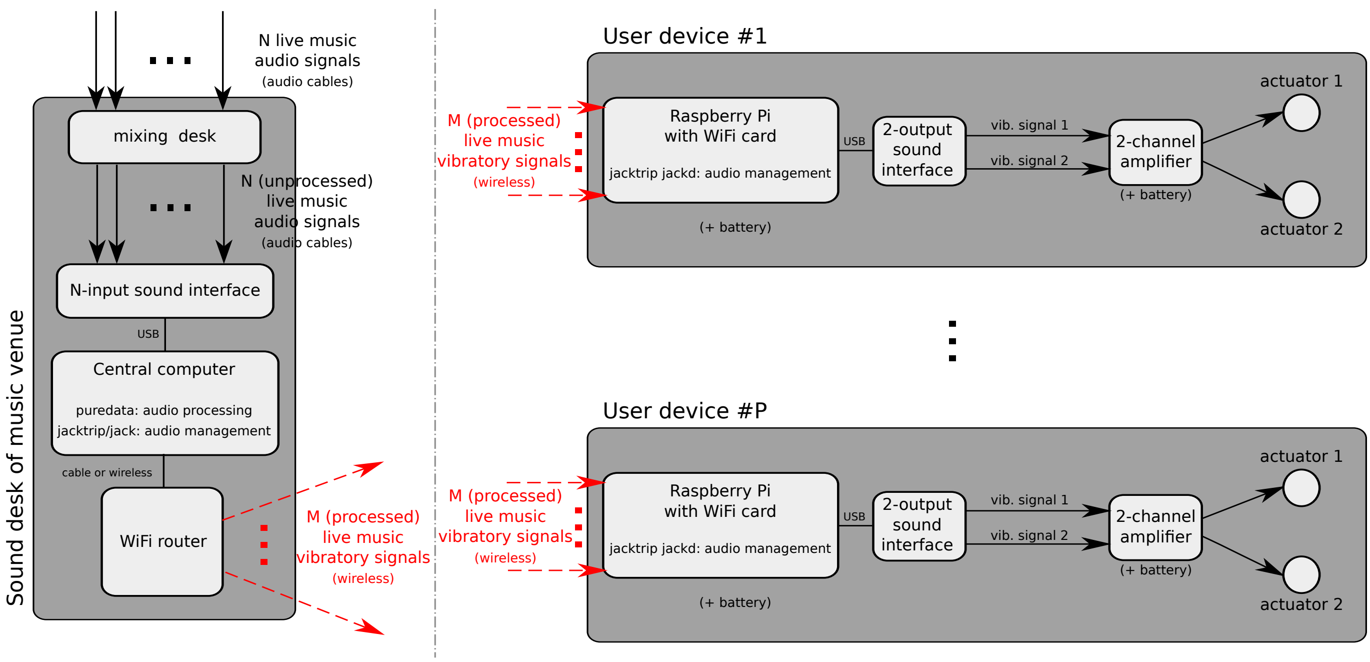

FIGURE 1 – Schematic view of the workflow of the proposed technological solution. Left : sound desk, central computer and sending of signals. Right : user devices receiving the signals and playing them over the actuators.

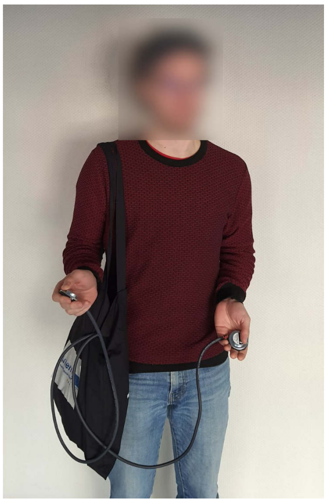

FIGURE 2 – A user with the user device in a textile bag and holding the two actuators in their hands.

2 channels for each user device because they are fitted with a two-channel amplifier and have two actuators. Further versions of the devices may use more output channels and take advantage of the virtually unlimited number of band-limited channels that can be transmitted over WiFi.

In terms of software implementation of this solution, we use tools that have been offered and maintained by the open source community for a long time. Provided the central computer and each user device run a `Linux` operating system and are connected to the same WiFi local network, the central computer uses `JACK`[5] as an audio server, routes `Pure Data`'s output to each device using the graphical tool `QjackCtl`'s[6] mapping abilities, combined with `jacktrip`[7] to send signals over the network (using unicast as an underlying transmission method, a solution that should be enabled by default in the WiFi network of concert venues and public spaces). Each user device receives the signals back with `jacktrip` as well (the first two channels are directly sent over the two outputs of the USB sound interface of the user device). This solution of communicating vibratory signals (processed as audio signals) over WiFi offers a considerable gain in flexibility : the operator has the choice of routing any signals to some / a group of / all the connected devices. Each device may therefore receive exclusive signals, the same signals as the others, or a combination of both.

Besides the flexibility, this solution will certainly lead to reducing costs. First, electrical consumption will be reduced as the *Raspberry Pi*s of each device no longer need to run a local instance of `Pure Data`. Second, money expenses and amount of material needed for each device will be reduced : HF-radio receivers are no longer required; concentrating all the computation on a single central computer makes it possible to dispense with `Raspberry Pi` in favor of lower-level, lower-power boards or nano-computers (provided they have a WiFi card and can connect to a — not necessarily USB — sound interface).

5. See https://jackaudio.org/, retrieved March 19, 2025.

6. See https://qjackctl.sourceforge.io/, retrieved March 19, 2025.

7. See https://github.com/jacktrip/jacktrip, retrieved March 19, 2025.

4 Perspectives

Ongoing effort is made on the update of methods for transforming sound into vibration. The previous implementation [11] chose a symbolic approach where the categorical value of some sound descriptor (e.g. if the spectral centroid is below or above a pre-defined threshold) is displayed as a change in the vibrotactile texture displayed (e.g. a sine wave versus a noisy signal), pretty much like the production of vibrotactile icons representing some aspects of the sound. Current implementation has opted for an analog approach, as an amplitude-modulation method where the envelope of the input sound signal drives (with more or less compression and adaptation to warrant perceptibility) the envelope of the output vibration signal. The carrier vibration signal (the one multiplied by the processed envelope) is based on a sine wave whose characteristics (amplitude, frequency, possible presence of harmonics, etc.) are driven by extracted features in the input audio signal (pitch, spectral centroid, spectral roll-off, attack time, etc.). This is inspired by previous work in the team [12].

In its present shape, the software implementation requires an operator to manually select the input channels that are going to be processed and sent over WiFi for display by the devices, and manually choose in the `Pure Data` patch the parameters of the sound to vibration conversion. Current work is being made to modify the `Pure Data` patch so that it can be dynamically modified according to user's remote requests made from a web-based form accessible on their smartphones.

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Références

[1] É. Mercier, A. Tétaz, S. Quétier-Parent, *Baromètre des Usages de la Musique en France*, CNM, IPSOS, Sopra Steria (2023).

[2] S. Brétéché, *L'écoute encorporée, ou l'émergence du sensible : De la corpauralité à l'écoute musicale sourde*, in X. Hautbois, M. Laliberté, L. Stransky and V. Stransky, *L'émergence en musique — Dialogue des sciences*, Éditions Delatour (2019).

[3] R. Verrillo, *Vibration Sensation in Humans*, Music Perception **9**(3), pp. 281–302 (1992).

[4] B. Remache-Vinueza, A. Trujillo-León, M. Zapata, F. Sarmiento-Ortiz, F. Vidal-Verdú, *Audio-Tactile Rendering : A Review on Technology and Methods to Convey Musical Information through the Sense of Touch*, Sensors **21**(6575) (2021).

[5] A. Flores Ramones, M. del-Rio-Guerra, *Recent Developments in Haptic Devices Designed for Hearing-Impaired People : A Literature Review*, Sensors **23**(2968) (2023).

[6] Y.-J. Cho, S.-U. Kim, M.-C. Joung, and J.-J. Lee, *Haptic Cushion : Automatic Generation of Vibrotactile Feedback based on Audio Signal for Immersive Interaction with Multimedia*, Proc. of the 14th International Conference on New Actuators, Bremen (GER), pp. 427–430 (2014).

[7] *Psychophysical comparison of the auditory and tactile perception : a survey*, S. Merchel and M. E. Altinsoy, Journal on Multimodal User Interfaces **14**, pp 271–283 (2020).

[8] F. A. Araujo, F. L. Brasil, A. C. Lima Santos, L. de Sousa Batista Junior, S. Pereira Fonseca Dutra, and C. E. Coelho Freire Batista, *Auris System : Providing Vibrotactile Feedback for Hearing Impaired Population*, BioMed Research International **2181380** (2017).

[9] I. Hattwick, I. Franco, and M. M. Wanderley *The Vibropixels : A Scalable Wireless Tactile Display System*, in S. Yamamoto, *HIMI, Part I*, LNCS **10273**, pp. 517–528 (2017).

[10] M. S. Puckette, *Pure data : Another integrated computer music environment*, Proc. of the second intercollege computer music concerts, pp. 37–41 (1997).

[11] A. Paté, N. d'Alessandro, A. Gréciet, and C. Bruggeman, *TOuch ThE Music : Displaying Live Music into Vibration*, in C. Saitis et al. (Eds.) : HAID 2022, LNCS **13417**, pp. 3–13, (2022).

[12] Q. Consigny, *Médiation vibrotactile : de la caractérisation physique à l'étude perceptive d'un transducteur électrodynamique*, Ph.D. Dissertation, Sorbonne Université (2023).