A SCALABLE HAPTIC FLOOR DEDICATED TO LARGE IMMERSIVE SPACES

Nicolas Bouillot
Société des arts technologiques [SAT]*
Montréal, Canada
nbouillot@sat.qc.ca

Michał Seta
Société des arts technologiques [SAT]
Montréal, Canada
mseta@sat.qc.ca

ABSTRACT

We present a haptic floor composed of tiles with independently controllable vertices and designed to cover arbitrary large flat surfaces. We describe the signal distribution architecture, based on SATIE, our spatialization engine and SWITCHER, our low latency and multichannel streaming engine. The paper also provides a description of several approaches of content authoring when such a floor is deployed in an immersive space. These approaches emphasizes the correlation among immersion modalities such as continuous localization of sound from the speaker system to the floor and continuous physical effect from the video projection to the floor.

1. HAPTIC FLOOR FOR LARGE IMMERSIVE SPACES

We question and experiment the extension of a large immersive space with a haptic floor covering the entirety of the surface. Largely motivated by augmentation of artistic venues with audience, we are interested in those with i) the ability to offer immersive listening for a group of people, ii) visual immersion, and iii) floor space allowing for a case-by-case configuration of audience position (sitting, standing, lying down) and along with configuration of performance space.

Not limited to the above characteristics, the haptic floor prototype we propose has a scalable design and a flexible authoring possibility, targeting tight relation with the audiovisual effect in the venue. Indeed, as demonstrated by the scientific literature, augmentation of immersion with haptics could increase the perception of virtual environments by an audience, more specifically when combined with immersive sounds and visuals. Vection[1], for instance, when stimulated by the actuators placed between the ground and the feet of a sitting subject, is obtained in a shorter time and with more intensity when the haptic feedback (constant frequency sinusoidal vibrations) is applied[1]. Similar results are obtained for a standing posture, without any impact on the impression of presence[2]. Haptic feedback can contribute to increased perceptive sensibility of an individual[3, 4]. The above cited research, however concern experiences involving individual users. From this point of view, developing a floor simulating haptic feedback of walking on particular ground textures[5], such as snow, offers an opportunity for a collective sensory experience.

Unfortunately the above cited research does not apply directly to our work. The devices employed in the previous research consider pre-determined posture of the subject, particularly in the case of walking. Other approaches and applications remain to be explored that offer creators an immersive and flexible space where different experiences can be quickly prototyped.

As our primary source of inspiration, our immersive space called the Satosphere (see figure 1) is a large dome-shaped audiovisual projection space offering the view of the horizon (floor to ceiling projection) and 360° at the same time. Over 11 meters high and 18 meters in diameter, the Satosphere is equipped with 157 loudspeakers grouped into 31 adjacent clusters on the dome's surface, and with 8 video projectors that distribute the video image across the dome's surface. Other venues around the world provide a listening environment for spatial audio, where our research could apply. The CUBE [6] of the Virginia Tech is an immersive space dedicated to sound. It offers a significant spatial resolution with its 124 audio channels and provides for audio spatialization techniques, including movement capture. The ALLOSPHERE [7] offers 360° vertical and horizontal immersion. The lack of a floor is compensated by a bridge, allowing to go to the center and experiment with different data visualization strategies and audio-visual immersive compositions. Unfortunately, this constraints the viewer to assume standing position and move only around the narrow bridge. Another example, in France, ESPACE DE PROJECTION at IRCAM provides rotating panels to offer several acoustic profiles[8]. It hosts 75 speakers arranged in a cube. Finally, the team at the Center for Computer Research in Music and Acoustics at Stanford University has developed the GRAIL[9], a system of 32 speakers and 8 subwoofers that can be deployed in different locations, such as outdoors, concert halls or studios. There are other venues equipped with speaker setups that accommodate listening to spatial music, a non-exhaustive list provides[10]: the IEM-CUBE and MUMUTH in Graz, the MULIT in Bergen, the MOTION LAB in Oslo, the SPACE in Pesaro and the DIGITAL MEDIA CENTER THEATRE in Bâton-Rouge.

Our work on the haptic floor is, to our knowledge, unique in treating the question of creation and reproduction of content for haptic feedback in the context of immersive space for groups of participants in non-specific postures (see figure 1). In this case, the device is designed to cover arbitrarily large surfaces, its hexagonal shape (see figure 2) allows for easy assembly and fitting into large, flat surfaces, such as the Satosphere's floor.

In this paper, we present the prototype of a floor built to provide haptic feedback during experiences designed to posture agnostic content created for large immersive spaces (Figure 1). Our prototype represents one segment of a device that could cover arbitrarily large floor surfaces and is driven by audio signals delivered via local network. It is integrated into our spatialization software, SATIE[11], therefore it is tightly coupled with the immersive content. This is illustrated by our demonstration video showing our floor integrated in an immersive space[2].

* Society for Art and Technology [SAT] is an artist center in Montreal specializing in dissemination of art made with new technologies with the focus on immersive arts and experiences.

[1] Illusion of self-motion

[2] See our demonstration video (accessed Dec. 2018): https://vimeo.com/290925507

(a) The audience can freely move around the space and interact with telepresent space or simply sit around the center (Miscible by Maotik and Manuel Chantre

(b) The audience is lying down and fills most of the floor space (Plateaux by Vincent Brault, Owen Kirby and Vincent Martin)

Figure 1: Examples of scenographies in our immersive space, illustrating the need for a haptic floor to be posture-agnostic, group-friendly and correlated with audiovisual displays.

2. OUR HAPTIC FLOOR PROTOTYPE

As seen in Figure 2, the hardware prototype is only one portion of the projected floor, consisting of a single hexagon divided in six triangles forming a mesh. An actuator is placed at each of the 7 vertices and is controlled individually with an audio signal ranging between 0 and 100 Hz for a height amplitude of 38.1 mm. The shape has been designed to easily scale up to the surface of larger space by multiplying the hexagonal components.

The signal distribution pipeline (Figure 3) consists of an audio renderer (a computer with ubuntu Linux 18.04) equipped with an appropriate audio I/O and a set of Raspberry Pis running Raspbian. Each RasPi is required to control three actuators (the *250i* model from our partner D-Box[3]). The audio renderer is based on a SuperCollider script combining specific signal processing and our spatialization engine SATIE described in more detail in section 3.1.

The audio renderer runs SATIE[4], our spatialization engine that provides for use of multiple spatializers in parallel[12]. In this case, one rendering is performed for entire haptic floor, along with the existing 8-speaker audio display (or the dome). The coupling of the haptic floor and speaker system allows for keeping some coherence in experience design, thanks to an internal per-rendering handling of the same OSC [13] message.

The audio renderer can handle a variety of inputs. Direct audio signals correspond to sound objects in SATIE that can be spatialized. OSC messages are interpreted in two possible ways, one with the SATIE protocols that allows for sound object control (location, spread, etc) and the other by controlling position of each actuator independently.

Audio spatialization is handled via an audio interface wired to the speaker setup. The haptic floor is handled via LAN connecting Raspberry Pi devices, each talking to a custom USB audio interface which controls up to 3 actuators (where one actuator affects one vertex of the floor's "mesh"). The latter allows for a flexible increase in number of floor subparts, adding *just* more Raspberries in the network.

On the software side, SATIE handles all input cases (audio and control signals) and performs spatialization for both the physical speaker system and the haptic floor. The audio signals destined for the traditional speakers are handled directly with the audio interface. The audio signals that control the haptic floor need to be sent over network to the Raspberry Pis. Low latency streaming from the audio renderer to the Raspberries is achieved using SWITCHER[5], our multichannel and low latency streaming engine. The transmission of audio streams from SATIE to switcher is done through the jack server.

3. AUTHORING FOR HAPTIC FLOOR

The challenge lies in designing haptic content that is appropriate to the type of immersive experience, and more particularly when sound and graphics are involved. Here follow some use cases where haptic floor control can be correlated with immersive content:

- locate the sound in the floor in order to continue a sound trajectory
- propagate waves from a sea displayed on screen to mechanical waves on the floor
- ripple effect as well as delivering of different types of haptic content to different areas of the floor at the same time, corresponding to drops falling from the sky
- control vibration of the floor according to the sound played

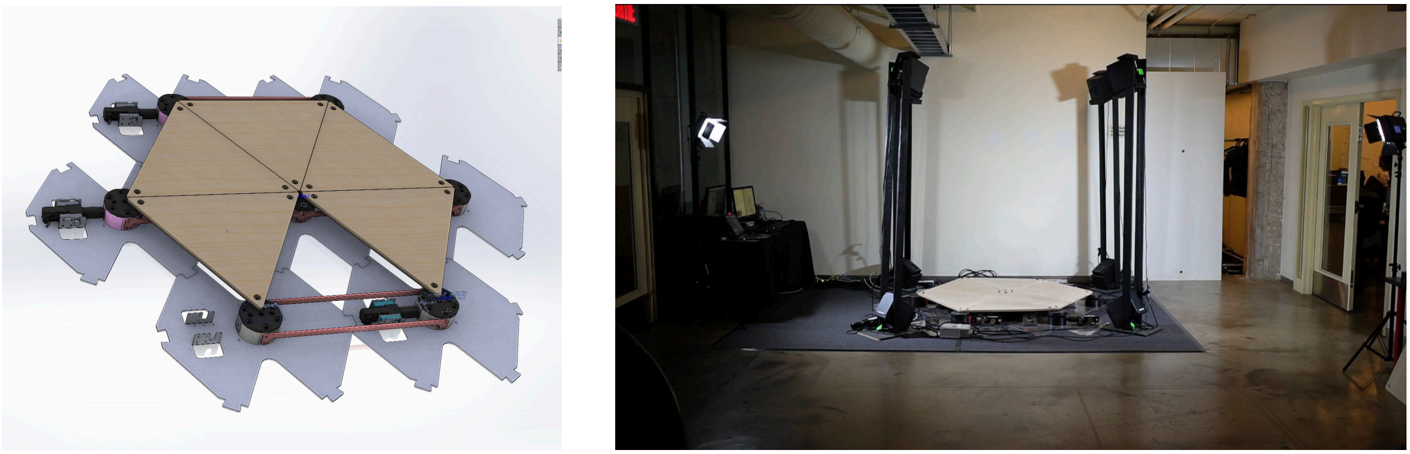
3.1. Audio spatializer based rendering

SATIE [11, 14], written in the SuperCollider language [15], provides rendering of virtual audio scenes spatialized over many audio chan-

[3]D-Box is a company which designs, manufactures, and markets actuators intended mainly for the entertainment and industrial simulation markets. `https://www.d-box.com/en`, accessed Dec. 2018

[4]`https://gitlab.com/sat-metalab/satie`, accessed Dec. 2018

[5]`https://gitlab.com/sat-metalab/switcher`, accessed Dec. 2018



(a) Concept drawing of one subpart of a larger haptic floor. 7 actuators (two of them, the black cylinders, can be seen on the left) are controlling each vertices independently.

(b) Our haptic floor prototype with a cube shaped 8 speaker system. We use the SATIE dual rendering feature in order to provide continuous spatialization among the speaker system and the haptic floor.

Figure 2: Hardware design of a floor subpart. The current prototype is only one section of the target haptic floor and.

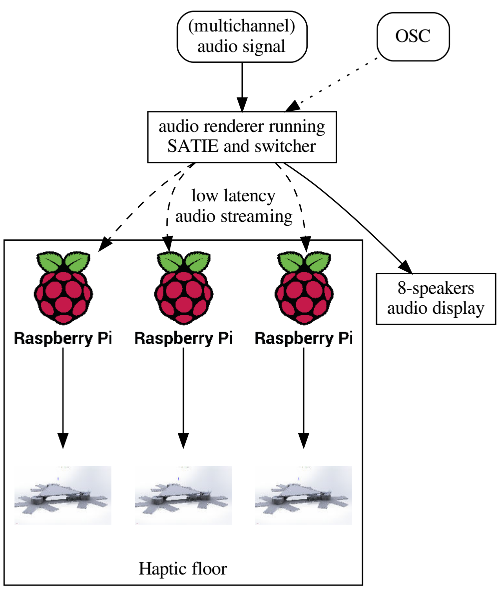


Figure 3: Distribution pipeline. Our prototype, in addition to : use three Raspberry Pis and three D-Box interfaces, each one controlling three actuators.

nels. We were able to build upon our previous experience with near-field/far-field audio rendering[12] and tackle the floor as another audio display because the provided actuators transforms digital audio signals to mechanical movement. This approach provides a few benefits. First of all, the synchronization of audio signals, after compensation for the delay between audio displays, is handled by SATIE and does not require any other work. Secondly, haptic content creation can be approached in parallel with audio creation and spatialization design.

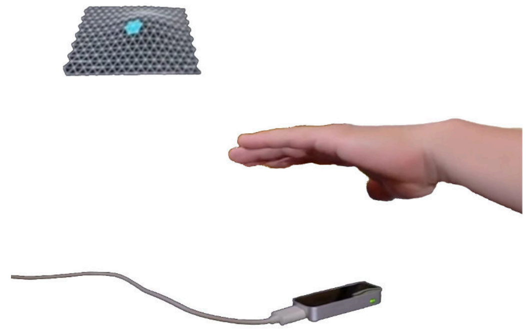
We have experimented with different approaches to spatial audio such as VBAP, ambisonics and a crude equal power panning. All types of audio spatialization work well and the choice of approach will depend on the desired effect and audio content. We also applied an envelope tracker filtering in order to convert audio signals into signals compatible with our actuators that respond well to frequencies between 0 and 100 Hz.

Moreover, since SATIE can handle many types of control inputs (audio, USB, network), it can still assist in delivering synchronized audible and haptic audio signals. Additionally we can take advantage of SuperCollider's powerful synthesis and DSP capacity to experiment and design audio signals suitable for the haptic floor with a lot of flexibility. Finally, the spatialization of audible audio signals and audio delivered to the haptic floor can be completely independent, which also offers the necessary creative freedom.

As one of our first experiments, in collaboration with D. Andrew Stewart[6], we explored the use of the floor prototype driven by 8 discreet channels of analog audio from an electronic performance instrument based on Omnisphere VST plugin, controlled by Karlax controller. The audio channels were spatialized as 8 independent sound objects on the octophonic, cube-shaped speaker layout, each acting on the floor depending on the spatialization parameters. We have experimented with OSC messages sent from Karlax directly to SATIE as well as via our interactive creation tool for immersive spaces, EIS[16]. Through this short experimentation with live performance, we found that using the sound of the instrument to drive

[6] `http://dandrewstewart.ca/`, accessed Dec. 2018

(a) Live control from Ableton (concept and development from Mourad Bennacer). The orientation from the device (left) is applied to the floor (right).



(b) Mapping with a 3D Mesh: the blue mesh (upper left) is a virtual representation of the haptic floor and part of a larger mesh. Here the hand detection with Leap motion (bottom) allows for *touching* the floor (Concept and development from Sébastien Gravel and Vincent Brault).

Figure 4: Authoring content for the haptic floor with other software (Ableton and Touch Designer) using an OSC protocol allowing real-time control of each actuator independently.

the movement and the texture of the floor creates a deep sense of coherence. In fact, placing performers on the floor can have its benefits.

3.2. Other approaches

The other approaches we describe here are based on the control of each actuator independently from Open Sound Control[17]. Messages from external software are composed of several float values ranging from -1 to 1, each one being the desired height of the corresponding actuator. Along with our audio spatializer based rendering, they are illustrated in our demonstration video[2].

The first one, illustrated in Figure 4a, is a live control from Ableton. The basic protocol has been implemented in Ableton where Ableton specific creations can be used in order to create a tight relation between the sound and/or an Ableton controller with the haptic floor. This allows, for instance, to program automated floor vibrations synchronized with the audio track. In our demonstration video, a simple mapping from the orientation of an accelerometer-equipped device with the orientation of the haptic floor has been implemented.

The second approach is a mapping of the floor with a 3D Mesh (Figure 4b) in a 3D software. Accordingly, any physics or interaction applied in the virtual environment becomes a source of vibration possibly applied to the floor. This provides the potential for strong correlation of the visual with the floor. With this approach for instance, sea waves from a simulation can be displayed from the screen with a consistent continuity in the floor. In our demonstration video, a hand tracking system, the Leap Motion, is used in order to move a virtual hill along a planar mesh.

4. CONCLUSION & NEXT STEPS

This paper has presented our experience with distribution architecture of a scalable haptic floor targeting posture-agnostic multi-person immersive spaces. The floor is scalable in space thanks to its triangular shape allowing for unlimited tiling. Its signal distribution scalability is ensured using low latency multichannel streaming to Raspberry Pis, each one dedicated to groups of three actuators.

Surprisingly, experiments with our prototype have pointed us towards an uncharted territory of haptic feedback, both from technological and creative points of view. This led us to describe in this paper a set of methods for authoring content for floor-involved immersive content: i) using the floor as an additional "audio display" driven by audio and/or using multi-speakers spatialization algorithm and ii) producing content from other software, including 3D graphic engine, with the help of a basic OSC protocol providing independent control of each actuator height.

Our next steps will be targeting experiments with a larger scale floor covering our dome with approximately 200 actuators. Along with physical design and construction methods, we will go forward with improvement of authoring methods for group of users and validation of the architecture scalability.

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