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Master's Thesis

Academic Year 2016

atmoSphere: Designing Cross-Modal Music Experiences Using Spatial Audio with Haptic Feedback

Keio University
Graduate School of Media Design

Haruna Fushimi

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
MASTER of Media Design

Haruna Fushimi

Thesis Committee:

Associate Professor Kai Kunze	(Supervisor)
Professor Naohito Okude	(Co-supervisor)
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Abstract of Master's Thesis of Academic Year 2016

atmoSphere:
Designing Cross-Modal Music Experiences Using Spatial Audio with Haptic Feedback

Category: Design

Summary

"atmoSphere" is a system that provides users immersive music experiences that allows them to " feel " sound in their body. I focused on cross-modality of auditory and haptic sensations in order to integrate immersion. "atmoSphere" consists of 3 elements; spatial audio music, a sphere shaped device, and haptic feedback.

Combining spatial audio and haptic feedback, atmoSphere enhances listening activity. Effects of cross-modality allow users not only to listen to music but also feel it.

Initial prototype of atmoSphere was exhibited in public demonstration, KMD Forum 2016. More than 30 participants experienced the demonstration. After some major improvements, final prototype was presented in atmoSphere demonstration session. 9 participants experienced the demonstration and their reactions and feedback proved that atmoSphere provided immersive music experiences.

Keywords:

Spatial Audio, Haptic Feedback, Cross-Modality

Keio University Graduate School of Media Design

Haruna Fushimi

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Chapter 1
Introduction

1.1 Motivation

"atmoSphere (Figure 1.1)" is a system that provides users immersive music experiences that allows users to "feel" sound in their body. "atmoSphere" consists of a spatial music and a device which provides haptic feedback. Users wear headphones and hold the sphere with both hands (Figure 1.2).

The music which users listen to is composed with spatial audio. It presents users a 3D stereo sound sensation. It means you can feel as if you were there. For example, you hear the sound that someone is clapping hands on your right although there is no one actually. For another example, you hear the sound that someone's footsteps circling around you. In conjunction with such stereoscopic localization of the sound, the sphere vibrates both hands of the user. The user can feel the movement of the sound with the haptic sensation by both hands, and can feel as though it is touching the sound. "atmoSphere" makes users entertained in the world of music through a synergistic effect of music composed so that sounds are heard from here and there and synchronized haptic feedback.

In order to design atmoSphere, I focused on effect of cross-modality between auditory and haptic sensations. I designed and produced 3 elements of atmoSphere; music, device, and haptic feedback. Music used in atmoSphere was composed with binaural recorded sound. The haptic device is a ball which has 8 transducers on the side face. Haptic feedback was designed so that users can feel the position and movement of vibrations which synced with the music.

There are two aims of atmoSphere. First is to enhance the experience of "listening" music. When we listen to the sound, we are not listening only by ears. Human perceptual representation arises from the integration of stimuli given to multiple sensory devices. In other words, interaction with modality such as visual sensation and haptic sensation works other than hearing as "listening" activity. There are interactions between auditory and other modalities. When we "listen"

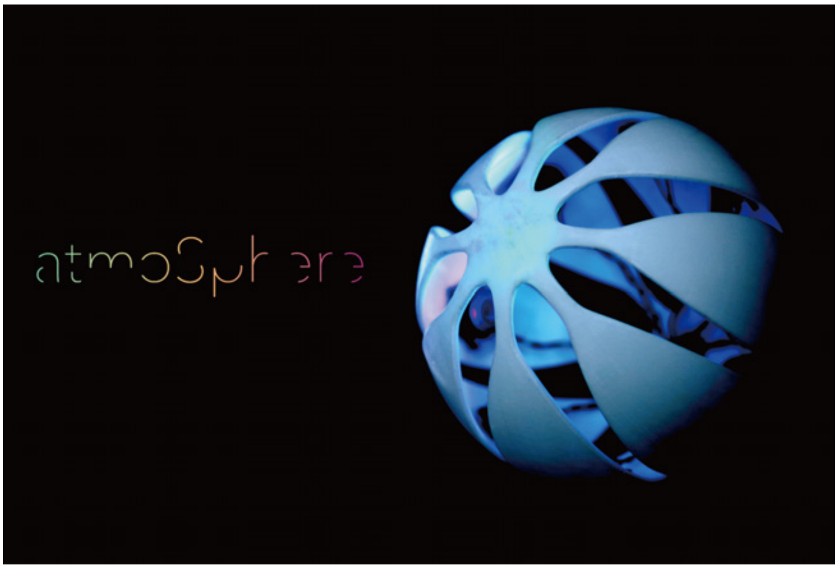


Figure 1.1: The Representative Photograph of atmoSphere

Figure 1.2: Demonstration of atmoSphere

to the sound, we actually "feel" the sound with visual and haptic sensations. "atmoSphere" creates music experiences that emphasize "feeling in the body" which is the essence of the "listening" activities.

Second is to present the possibility of VR experiences focusing on modality other than visual sense. Generally speaking, VR tends to imagine HMD, however visual elements are not necessarily essential. Furthermore, it is known that information integration among multiple modalities provides grounds for presence and reality. "atmoSphere" manipulates spatial perception with spatial sound and haptic feedback. It is pursuing a VR experience that does not rely on visual expression using HMD which has been mainly focused so far. "atmoSphere" pursues a VR experience that does not rely on visual representation using HMD which has been generally focused.

My research motivation radically based on my personal experience. From 2015 to 2016, I had participated in "Jack and the Beanstalk" project. It makes me interested in a relationship between music and haptic feedback.

" Jack and the Beanstalk (Japanese title: Nyoki-Nyoki Mamenoki) " is a VR game uses rope device and CG, expressing the experience of climbing to height. This work attempts to encapsulate the experience of thrills through immersing in a virtual reality game while interacting with a climbing rope device. As the name suggests, the game is deeply rooted around the the fairy tale, " Jack and the Beanstalk " .

We developed this system to submit a contest, the 23rd International collegiate Virtual Reality Contest (IVRC) [1]. It receved Laval Virtual Award and a VRSJ Award (the Runner-Up Award) . In March 2016, "Jack and the Beanstalk" was exhibited in Laval Virtual 2016 [2] held in France (Figure 1.3). It got a high evaluation.

In this project, I was in charge of graphic and sound design. After the Second stage (Prototype demonstration in VRSJAC 2015) of IVRC, we decided to add haptic feedback to improve the experience accompanying the physicality of pulling the rope. The chair has a large actuator. It provides users haptic feedback of sound effects. For example, when they hear the roar of a demon, they also feel vibration from the chair. It enables them to feel as if there is a demon. In this case, cross-modality of auditory and haptic sensation was effective way to increase immersion.

The frequency band that the actuator can present is about 200 Hz or less. Therefore, we used high cut filter to extract the frequency band which becomes vibration. The transducer under the chair is presenting to the suspended subjects so that the vibration does not disperse from the foot. It allows them to feel well haptic feedback in their body.

I realized that haptic feedback has a large impact on immersive feeling through this project. On the other hand, I felt that there is still room for improvement regarding sound. All background musical pieces and sound effects I made were just common two-channel stereo sound. I found that we should consider more about creating the impression of sound heard from various directions, as in natural hearing. In addition, I was convinced that a collaboration of spatial sound (like binaural sound or VR sound) and haptic feedback makes interesting VR music experiences.

Figure 1.3: Demonstration of "Jack and the Beanstalk" in Laval Virtual 2016

1.2 Research Background

It is a common saying that 2016, the last year was the year of virtual reality. High-quality Head Mount Displays including OCULUS Rift appeared in this year. In this situation, a problem is still being discussed.

"*How to create immersive VR experiences?*"

Up until now, VR systems have mainly focused on one out of the human ' s five senses, the visual. However, It ' s important to think about other senses. It is clarified that realism and immersion of a VR system can be greatly increased if we have at least two sensation of feedbacks in cross-modality.

In fact, there are many researches about cross-modality. These 3 points should be specially mentioned. First, the contents of perception is constructed by interaction and integration of information from multiple modalities. Second, integration of information between each modalities will be foundations of realism and immersion. Third, realism and immersion of a VR system can be greatly increased if we have at least two sensation feedbacks in cross-modality.

Therefore, these studies indicate that cross-modal interaction is the efficient way to increase immersion in VR.

1.3 Contributions

The contribution points of this study are as follows:

(1) Provide music experiences that emphasize "feeling in the body"
"atmoSphere" creates music experiences that emphasize "feeling in the body" which is the essence of the "listening" activities.

(2) Suggest New Point of View to Compose Music
Added the point of view, collaboration of spatial music and haptic feedback.

(3) Suggest New Type of Haptic Interface
A haptic device was implemented in this study. This interface has capability for application. For example, VR game, watching movie, etc.

1.4 Thesis Overview

This thesis consists of five chapters.

Chapter 1 is an introduction for this thesis. It explains contributions of this study. Chapter 2 shows literature review. Chapter 3 shows story of concept making, and finally suggests the designed artifact, atmoSphere. Chapter 4 describes final prototype of atmoSphere. It includes the evaluation of the prototype. Chapter 5 chapter presents summary and conclusion of this thesis.

1.5 Key Terms

atmoSphere

"atmoSphere" is the designed artifact in this study. It is consists of spatial music, a sphere shaped device, and haptic feedback. Details are in Chapter 3.

VR

VR = Virtual Reality.

Spatial Audio

Method to reproduce the direction, distance, and spread of three-dimensional sound at the time of recording or reproduction.

Chapter 2
Literature Review

2.1 Design of Spatial Audio

An art installation "Sound Forest [3]" based on concept similar to atmoSphere. consists of tactile-sound devices, a spatial sound constructing space. Users can feel sound through their acoustic and haptic senses and communicate with the space.

2.2 Haptic Feedback

There are some method to present haptic feedback. In this study, the haptic design method which proposed in TECHTILE toolkit [4] was adopted. This method has utility in that it makes it possible to use haptic device in the same way as using sound device. This haptic design method is also adopted in Synerstasia Suit [5] project. It proposed carefully designed vibro-tactile sensations on entire body make immersion.

Other studies have concluded that using multiple vibrators is effective way to make immersive experience. It was clarified that a low-resolution grid of inexpensive vibrating actuators can generate high-resolution, continuous, moving tactile strokes on human skin, in Surround Haptics [6] . It enables us to draw " tactile strokes " on a user ' s skin [7] . They also proposed Po2[Israr et al. 2015], which shows illusion of tactile sensation for gesture based games by providing vibrations on the hand based on psycho-physical study. "Po2 [8]" uses illusion of tactile sensations on gesture-based gameplays. Po2 system has two vibrating actuators and renders illusory tactile motion on your hands.

2.3 Cross-modality of Auditory and Haptic Sensations

Self-motion perception has explored in virtual reality research field. It have clarified that audio sensation alone can provide a self-motion illusion to the participant [9] Furthermore, other study shows that adding vibrations to audio enhanced such illusion [10].

In the study of auditory modulation by using tactile stimulation [11], they investigated cross-modal relationships between the two modalities, focusing on loudness and frequency.

Reality Jocky [12] proved effectiveness of the cross-modality in the user study and the public demo. It was suggested that the spatial moving sound gave users the illusion that the vibration source was also moving. It means that a combination of haptic and auditory sensation augments your spatial perception.

Chapter 3
Concept

3.1 Concept Making

3.1.1 Initial Idea

The concept of atmoSphere based on an idea that combination of spatial audio and haptic feedback enhances user's spatial perception. "atmoSphere" makes users entertained in the world of music through a synergistic effect of music composed so that sounds are heard from here and there and synchronized haptic feedback.

3.1.2 Concept

I defined the concept of atmoSphere based on this initial idea. It is "Providing users immersive music experiences that allows users to 'feel' sound in their body". The word " feel " means not only listen to music but also " feel " music in their body. In other words, providing users immersive music experience and making users listen to music attentively.

The concept put into a visual image. Figure 3.1 is a concept drawing of atmoSphere. Users wear headphones and hold the sphere with both hands. They can listen to music composed with spatial audio. It presents users a 3D stereo sound sensation. It means you can enjoy realistic sound as if you were there. The small sphere consists of some parts. Each of them has an actuator (sound tactile transducer) and it provides vibration. Users can feel the movement of the sound with the haptic sensation. This study excludes the visual sensation and focuses on the cross-modal effect of auditory and haptic sensation. Therefore, a LED in a small sphere is an optional function. A big sphere like a dome present audio visualization is also just an option. Based on these concept image, the following essential conditions were defined for designing atmoSphere;

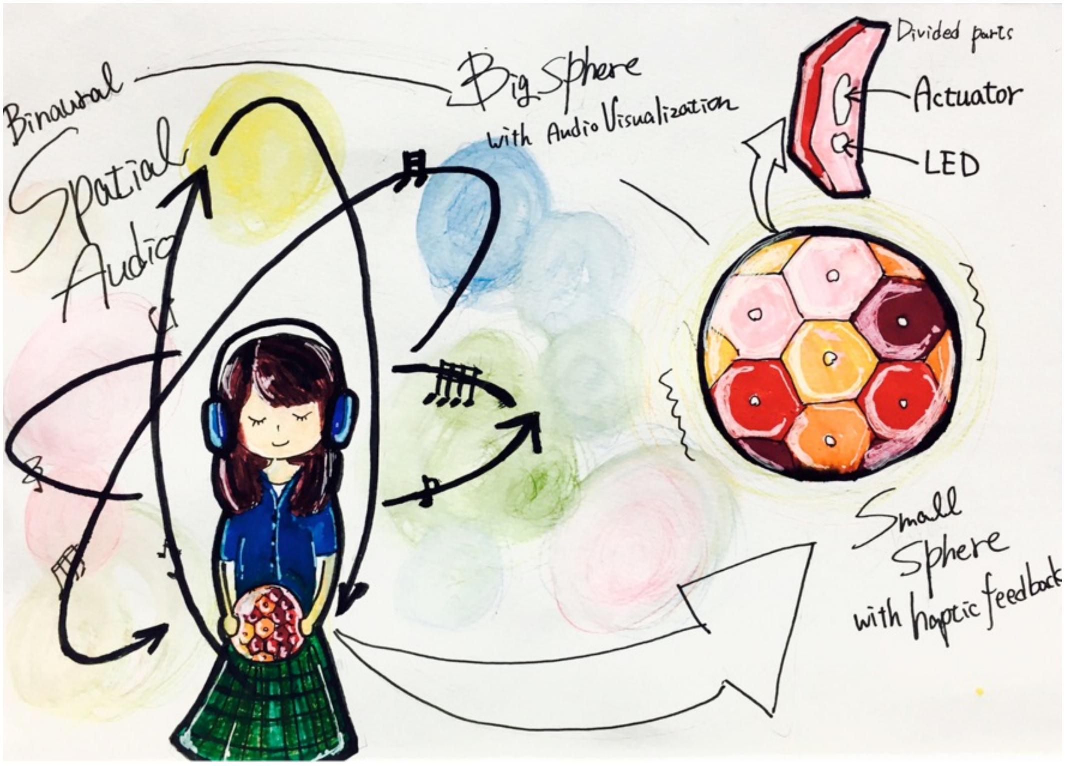


Figure 3.1: Concept Drawing of atmoSphere

(1) Spatial audio music
Spatialized music which produce immersive feeling.

(2) Sphere shaped haptic device that can be held with both hands
A handy size device anyone can handle with both hands was required. Avoid wearing type to make it easy to experience.

(3) Haptic feedback
The device provides users vibration.

Each of 3 elements discuss in the next chapter

3.2 Designing 3 elements of atmoSphere

3.2.1 Spatial Audio Music

Spatial audio is a method to reproduce the direction, distance, and spread of three-dimensional sound at the time of recording or reproduction. There are some some different ways to treat spatial audio. In this study, I tried some approach using 3D Sound Simulation like Google Cardboard SDK [13], and Oculus Audio SDK [14] at the first time. However, I decided to adopt binaural recording method because It makes more reality and immersion in quality of sound field reproduction.

Field Recording Using Binaural Microphone

As the first step, I tried binaural recording using microphone-equipped earphones. It capture what you hear, then listen back instantly. I tried field recording in Heidelberg (Germany), on September 16th, 2016. I walked outside with a linear PCM recorder TASCAM DR-07MKII and a binaural microphone Roland CS-10EM (Figure 3.2).

This field recording had two objectives. One thing is to try the first binaural recording. The other is to collect various kinds of sounds that could be used for music composition. As a result, the recording was successful, however the sound was less in reality. It was clarified that it is necessary to use more high-spec binaural microphone to record high-reality sound.

Figure 3.2: Equipments for Field Recording

Figure 3.3: Field Recording in Heidelberg

Trial Recording Using Dummy Head

Trial recording using dummy head is held in Miraikan, November 11th, 2016. I prepared several materials and tools like water, a watering can, a bottle, and gel (Figure 3.4). I used dummy head NEUMANN KU100 [15] which is the highest quality of binaural stereo microphone. As a result, water sounds using bottle makes interesting binaural audio (Figure 3.5 - 3.7).

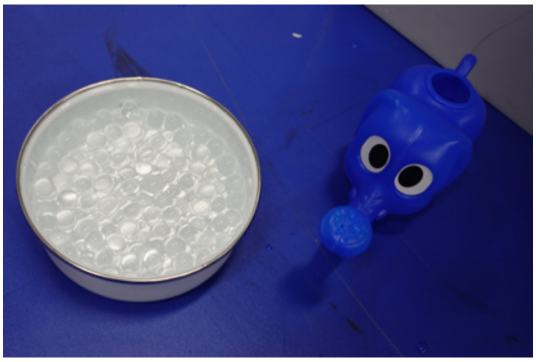


Figure 3.4: Examples of Materials

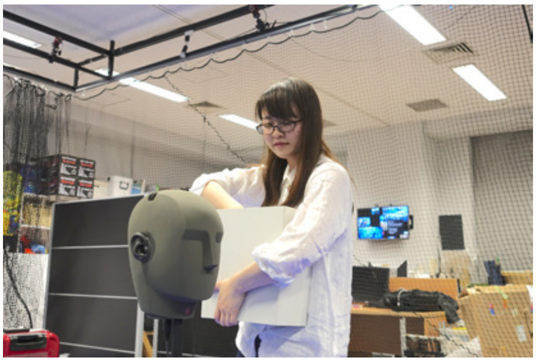


Figure 3.5: Recording Water Sound

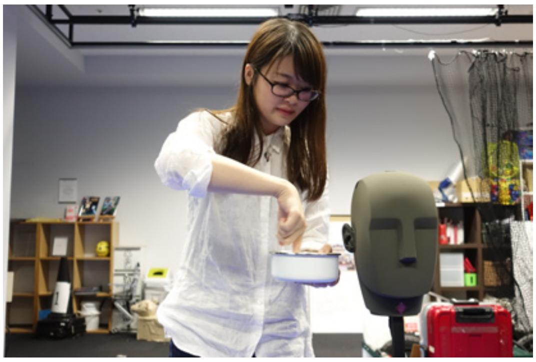


Figure 3.6: Recording Gel Sound

Figure 3.7: Making Some Noise Using a Bottle

Final Recording of Binaural Audio

Final recording held in Media Studio, Collaboration Complex, Keio Hiyoshi Campus on November 17th. I recorded many different kinds of sounds and created binaural sound library. After that, choose some sounds and load them to Apple Logic Pro X [16]. Figure 3.8 shows recording settings. I recorded clap sound (Figure 3.9) and whisper voice (Figure 3.10), and music output from the speaker from 8 directions (Figure 3.11).

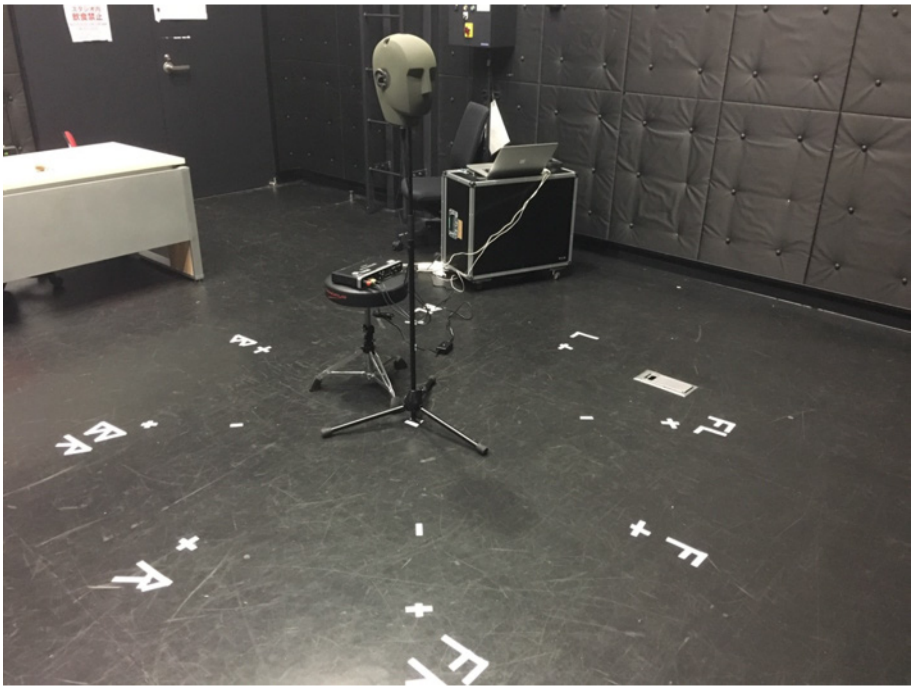


Figure 3.8: Setup for Recording

Composing Music Using Binaural Audio

I created binaural sound library. Some sounds in the library were chosen, then loaded to Logic pro X. I composed music with them. I also used sounds that were not binaural recorded so that users can contrast binaural sounds and the others.

Figure 3.9: Recording Handclap

Figure 3.10: Recording Whisper Voice

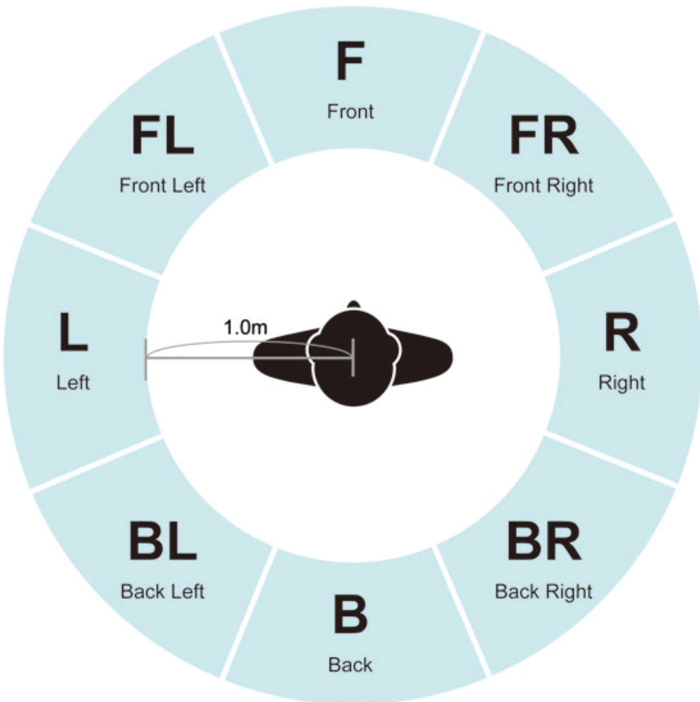


Figure 3.11: Image of Localization of Audio Sources

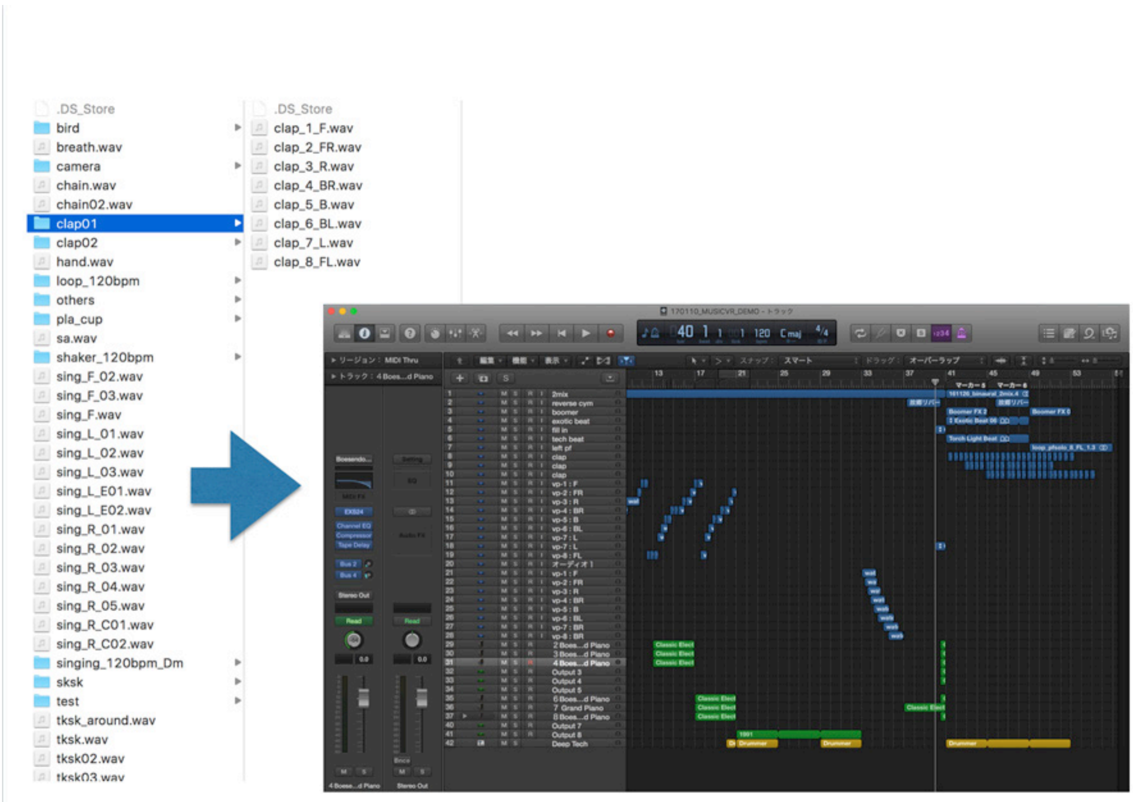


Figure 3.12: Loading Binaural Recorded Sound to Logic Pro X

3.2.2 Haptic Device

Requirements

(1) Sphere Shape
A sphere shaped device is linked the image of sound field (FIgure 3.11). It is necessary in order to provide users spatial motion of tactile feeling corresponding to spatial audio.

(2) Handy Size
Hands (fingers) are the most sensitive to touch sensitivity. Handy sized device make users easy to try atmoSphere because you can use without wearing anything. Users can handle it easily.

(3) 2 or 3 parts can be touched with one hand
When the ball is divided into 8 parts, more than 2 parts should be touched with one hand so that users can feel the movement of vibration.

Rapid Prototype

Figure 3.13 shows a rapid prototype of haptic device. This prototype is just like mock-up which is made of gel aromatic and LED, so that it does not have any function.

Define the Size of a Sphere

I collected 3 balls for reference; a volley ball (ϕ 660), a soccer ball (ϕ 600), and a toy ball(ϕ 460) (Figure 3.14). The toy ball, the smallest one was just right to hold with the hands. When the ball is divided into 8 parts, the user can touch 2 or 3 parts. However it is too small to put 8 transducers (sound tactile transducer Vp2 is ϕ 430). Finally adjusted to ϕ 500.

3D Printed Exterior

The exterior of a sphere was modeled, then 3D printed. The material is ABS resin. Figure 3.15 and 3.16 show 2 prototypes of haptic devices. The right one is the initial prototype, and the left one is the final prototype. Each of these will be described subsequently.

Figure 3.13: Rapid Prototype of a Device

Inside of Haptic Device

Figure 3.17 shows inside of haptic device. The sphere consists of 8 divided parts. Each part has a tactile sound transducer. There is a cushioning material between a transducer and an exterior because vibration from a transducer made some noise when I put it directly on an exterior.

Figure 3.14: 3 Balls for References

Figure 3.15: 2 Prototypes (top view)

Figure 3.16: 2 Prototypes (side view)

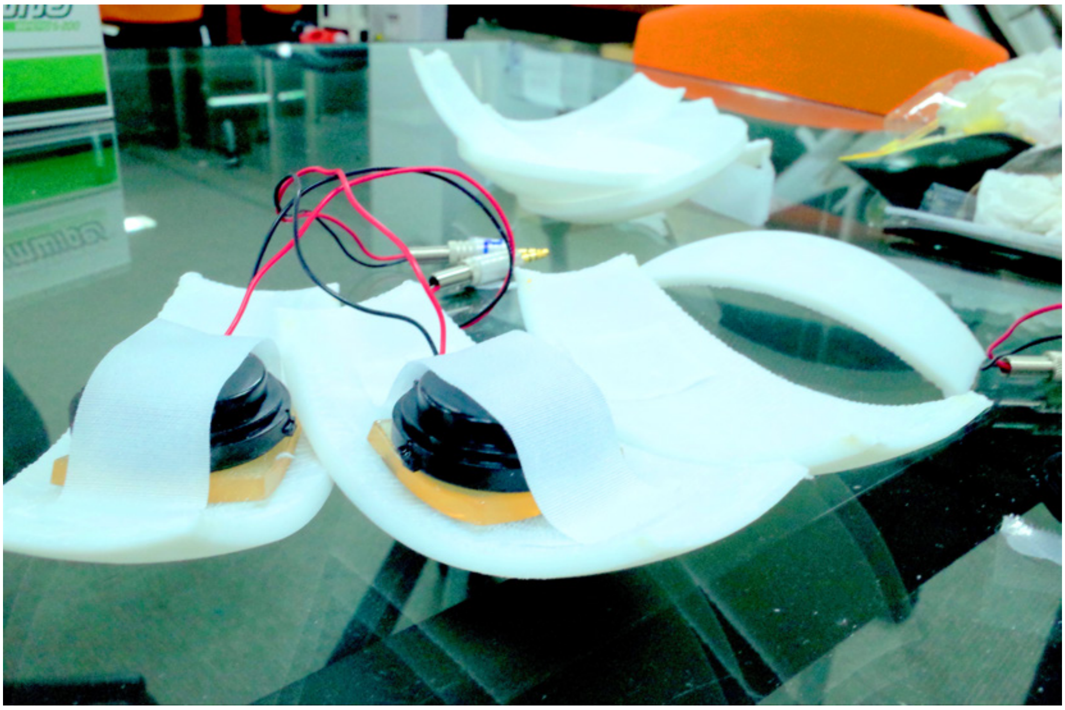


Figure 3.17: Inside of a Device

3.2.3 Haptic Feedback

Tactile Presentation Using Vibration

Tactile signals is played as audio signals (Figure 3.18). The frequency band that the oscillator can present is less than about 200 Hz. Using the equalizer and pitch shifter, I extracted the frequency band that becomes vibration and presents haptic sensation.

Audio signals for haptic feedback were carefully designed. The device does not provide feedback of all sounds. Because when all the sounds played with haptic feedback, users can ’ t recognize which vibration corresponds to which sound. In addition, persistent vibration reduces users sensitivity of vibration. Therefore, I added small-vibration parts, and none-vibration parts.

Figure 3.18: Filtering Audio Signals

Motion Synchronization

Users can feel spatial motion of haptic from the device. The movement of haptic sensation is corresponding the movement of binaural recorded sound which you are listen to (Figure 3.19).

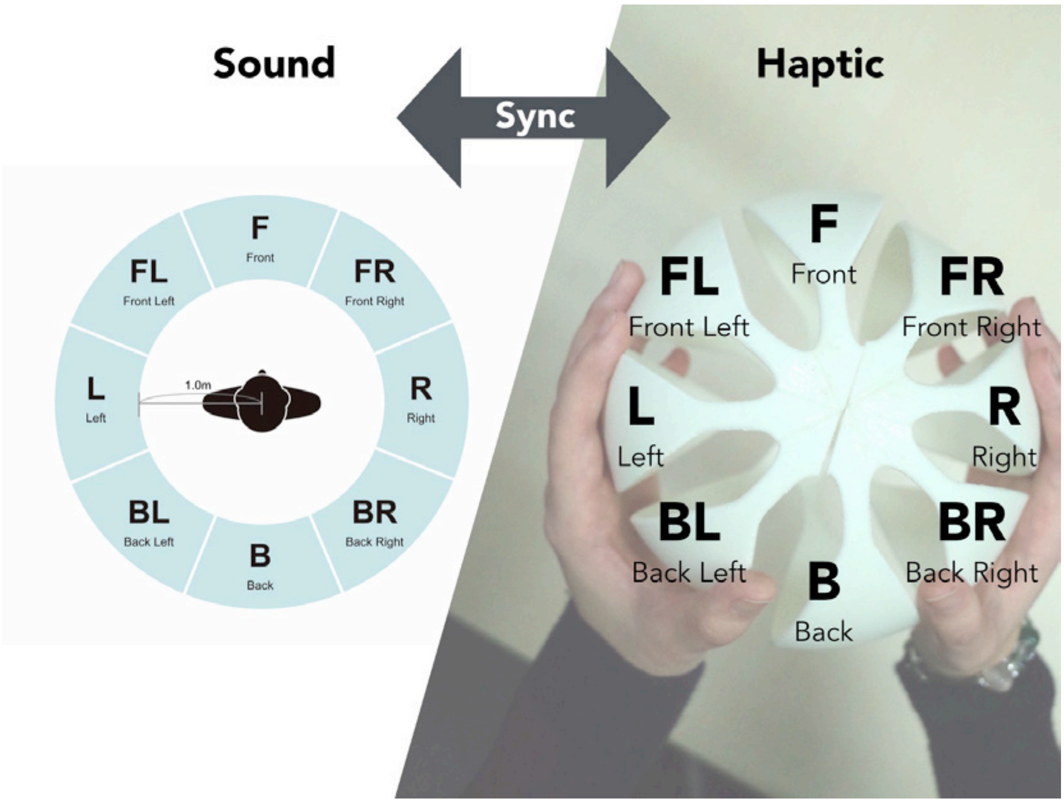


Figure 3.19: Synchronization of Spatial Audio and Haptic Feedback

3.3 Initial Prototype

3.3.1 Designed Artifact

Figure 3.20 shows the initial prototype of atmoSphere.

Figure 3.20: Initial Prototype of atmoSphere

3.3.2 System Overview

Figure 3.21 shows system overview of atmoSphere. The system consists of a USB audio interface(Roland UA- 1010), 4 amplifiers (Lepy P-2424A), 8 tactile sound transducers (Acouve Labora- tory Vp2), a USB-audio transducer (PLANEX PL-US35AP), a noise-cancelling headphone (Boss QuietComfort 35), a 3D printed sphere made of white ABS resin. This initial version of the device consists of 10 divided parts. Each of 8 part on side has a tactile sound transducer (Figure

3.17). DAW software Logic ProX was used for multi-channel output. 9 ch of audio signals were branched with a its software mixer.

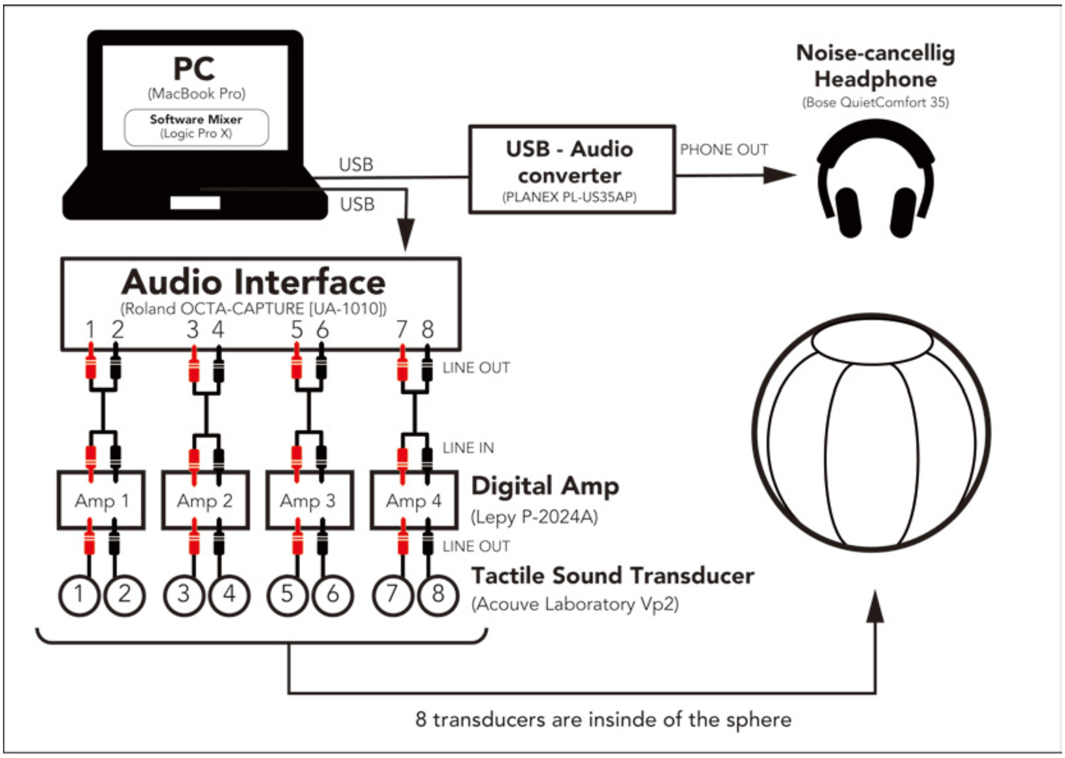


Figure 3.21: System Overview of atmoSphere

3.4 User Test - Public Demonstration in KMD forum 2016

3.4.1 Conditions

I had a chance to do a public demonstration of atmoSphere at KMD Forum that held in Keio University Mita Campus on November 26, 2016. During 9 hours in a day, more than 30 participants experienced the system.

3.4.2 Reactions

Figure 3.22 - 3.26 show reactions of participants. When observing the participants, the following reactions were seen;

- Some participants closed their eyes even if we did not instruct them to close their eyes.
- Some participants looked behind when hearing binaural recorded footsteps.
- There were participants held a device with arms.

3.4.3 Feedback

I interviewed the participants after the experiences. Examples of their comments are as follows;

- It really seems that someone is walking around me.
- I do not feel the hardness of the device.
- Vibration movement is difficult to understand.
- The device is comfortable to embrace.
- I got tired of having a device all the time.
- The vibration of the piano was a fresh feeling, I like it. Because I do not usually feel the sound of the piano as vibration usually.
- I get tired of similar vibrations continuing.
- I want a texture as well as the sound of water.

3.4.4 Discussion

Participants' reactions and comments showed that atmoSphere provided fun music experiences. The act of listening with closing eyes suggests that atmoSphere could provide them immersive experiences. Especially, 2 major problems were revealed. First, vibration movement is difficult to recognize. Second, users got tired of continuing similar vibrations. Therefore, I made some improvement for final prototype focusing on the device and haptic feedback. The updates and the final prototype will be introduced in the next section.

Figure 3.22: Demonstration of atmoSphere in KMD Forum 2016, No.1

Figure 3.23: Demonstration of atmoSphere in KMD Forum 2016, No.2

Figure 3.24: Demonstration of atmoSphere in KMD Forum 2016, No.3

Figure 3.25: Demonstration of atmoSphere in KMD Forum 2016, No.4

Figure 3.26: Demonstration of atmoSphere in KMD Forum 2016, No.5

3.5 Final Prototype

3.5.1 Designed Artifact

I made a new prototype based on findings from the user test. Figure 3.27 - 3.32 show a basic setup of final prototype of atmoSphere.

Figure 3.27: Final Prototype of atmoSphere

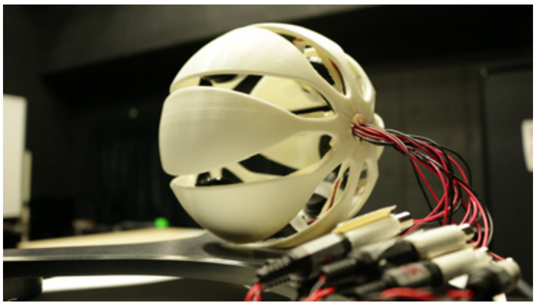


Figure 3.28: atmoSphere (back view)

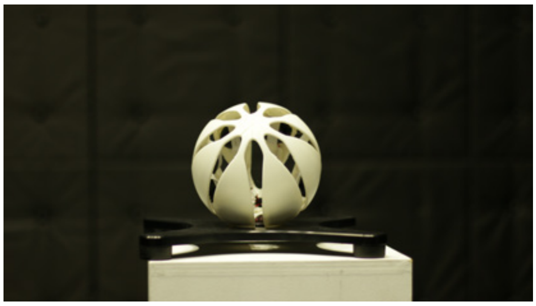


Figure 3.29: atmoSphere (front view)

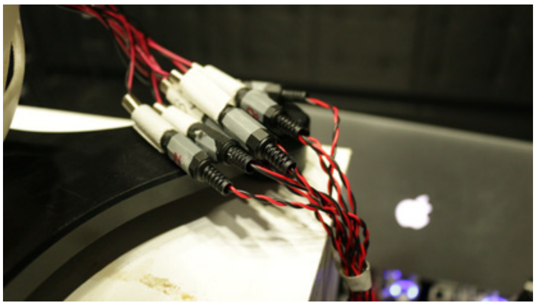


Figure 3.30: Wiring

Figure 3.31: Amplifiers and Audio Interface

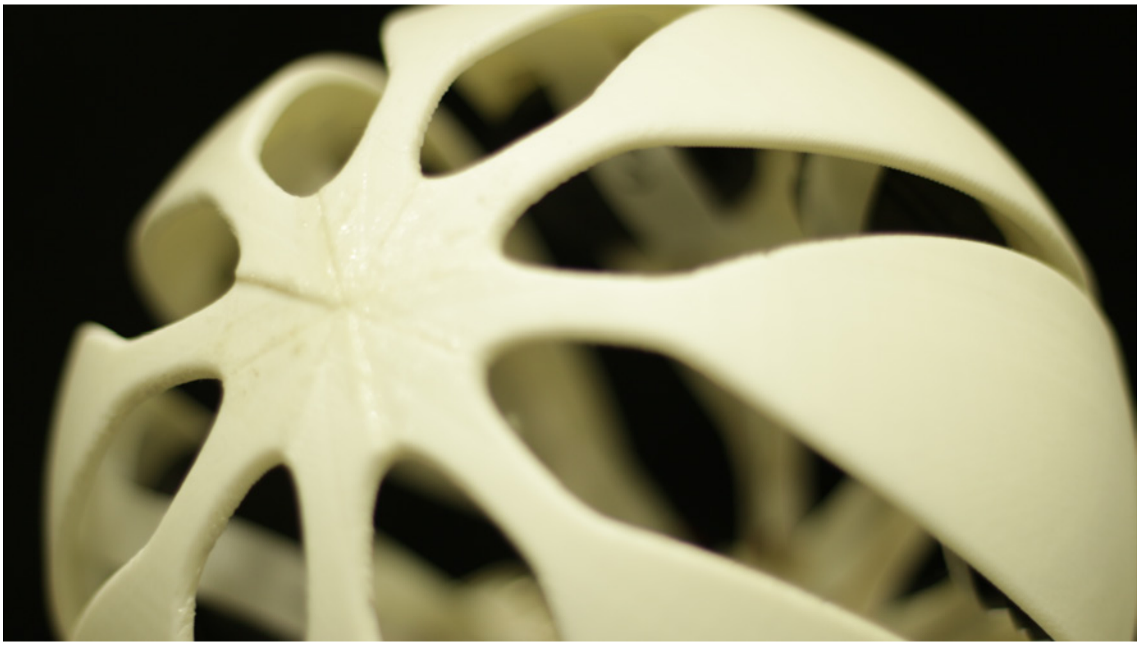


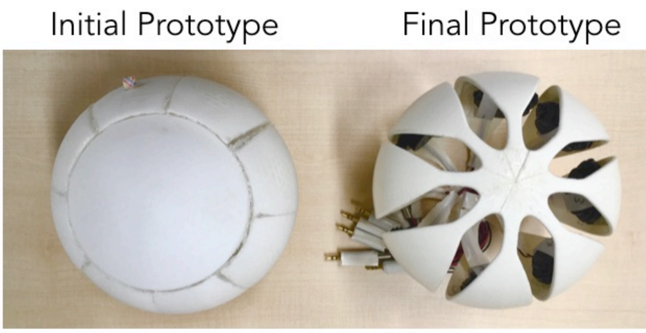
Figure 3.32: atmoSphere (enlarged view)

3.5.2 System Overview

The system of this final prototype is basically the same as initial prototype (Figure 3.21).

3.5.3 Updates

Figure 3.33 is comparison of the initial prototype and the final prototype. It shows major updates. Especially, the shape of the sphere was greatly changed, in order to make it easier to recognize which part of sphere vibrates. Vibration patterns are also improved. It increase synchronization between haptic feedback and sound.



		Initial Prototype	Final Prototype
Device	Shape	close set of sphere	loose set of sphere
	Thickness of Cushion	5.0 mm	2.5 mm
Vibration Patterns	Footsteps	All actuaters vibrate.	Correspond to rotation of binaural audio
	Water	No haptic feedback	Correspond to rotation of binaural audio

Figure 3.33: Final Prototype of atmoSphere

Chapter 4
Proof of Concept

4.1 Method

A demo session of atmoSphere was held to prove the concept; providing users immersive music experiences that allows users to “ feel ” sound in their body. Participants tried 2 minute demonstration of atmoSphere (final prototype), then I got verbal feedback from users.

4.2 Conditions

Time and Date
19:00-20:00, on Wednesday, January 11, 2017.

Place
Media Studio, Collaboration Complex, Keio University Hiyoshi Campus

Number of Participants
9

4.3 Results

4.3.1 Reactions

Figure 4.1 - 4.7 show reactions of users. Some participants closed their eyes and listened attentively to music (Figure 4.1 - 4.3). Other participants smiled when they found interesting sounds or tactile feelings (Figure 4.4 - 4.7).

Figure 4.1: Demonstration of atmoSphere in Media Studio, No.1

Figure 4.2: Demonstration of atmoSphere in Media Studio, No.2

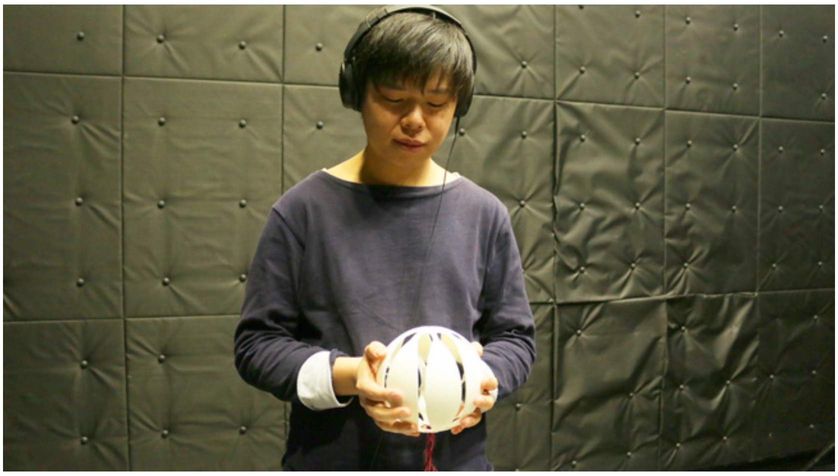


Figure 4.3: Demonstration of atmoSphere in Media Studio, No.3

4.3.2 Feedback

Some of comments from users are as follows;

- It really seems that someone is walking around my head.
- It was interesting that vibration moved corresponding to binaural audio.
- I felt a texture of water. I felt as if the device was cold.
- This is fun!
- I felt as if I was touching sound.
- Listening to the footsteps, I turned backwards reflexively.

4.4 Discussion

The concept of atmoSphere is "Providing users immersive music experiences that allows users to 'feel' sound in their body". The word "feel" means not only listen to music but also "feel" music. In other words, providing users immersive music experience and making users listen to music attentively. As a result, their reaction and feedback showed that atmoSphere provided users immersive music experiences that allows them to "feel" sound in their body. In addition, effects of cross-modality was also confirmed. For example, they felt texture of water.

Figure 4.4: Demonstration of atmoSphere in Media Studio, No.3

Figure 4.5: Demonstration of atmoSphere in Media Studio, No.4

Figure 4.6: Demonstration of atmoSphere in Media Studio, No.5

Figure 4.7: Demonstration of atmoSphere in Media Studio, No.6

Chapter 5
Conclusion

5.1 Summary

"atmoSphere" is a system that provides users immersive music experiences that allows them to "feel" sound in their body. I focused on cross-modality of auditory and haptic sensations in order to integrate immersion. "atmoSphere" consists of 3 elements; spatial audio music, a sphere shaped device, and haptic feedback.

Combining spatial audio and haptic feedback, atmoSphere enhances listening activity. Effects of cross-modality allow them not only to listen to music but also feel it.

Initial prototype of atmoSphere was exhibited in public demonstration, KMD Forum 2016. More than 30 participants experienced the demonstration. After some major improvements, final prototype was presented in atmoSphere demonstration session. 9 participants experienced the demonstration and their reactions and feedback proved that atmoSphere provided immersive music experiences.

5.2 Extensibility

"atmoSphere" surely has potential for applications outside of music field. It can be used for haptic interface for games, watching movie, meditation, etc.

5.3 Future Works

Actually, this project is still going on as of 3 February, 2017.

On the academic side, we are planning to submit papers to several conferences. Psychophysical validation will be conducted on the effect of cross modality between spatial sound and handy tactile feeling.

On the art and design side, we are also planning to apply to several contests. We are making a new prototype to improve completeness as a designed artifact; painting the exterior in order to make it look beautiful, making the wiring simpler, and making it easy to disassemble.

References

[1] VRSJAC ivrc 2015. `http://ivrc.net/2015/`. Accessed: 2017-02-03.

[2] laval virtual. `http://www.laval-virtual.org/en/`. Accessed: 2017-02-03.

[3] VRSJAC ivrc archive - sound forest(2010). `http://ivrc.net/archive/soundforest2010/`. Accessed: 2017-02-03.

[4] Kouta Minamizawa, Yasuaki Kakehi, Masashi Nakatani, Soichiro Mihara, and Susumu Tachi. Techtile toolkit: a prototyping tool for design and education of haptic media. In *Proceedings of the 2012 Virtual Reality International Conference*, page 26. ACM, 2012.

[5] Yukari Konishi, Nobuhisa Hanamitsu, Kouta Minamizawa, Ayahiko Sato, and Tetsuya Mizuguchi. Synesthesia suit: the full body immersive experience. In *ACM SIGGRAPH 2016 VR Village*, page 20. ACM, 2016.

[6] Ali Israr, Ivan Poupyrev, Chris Ioffreda, Jim Cox, Nathan Gouveia, Huw Bowles, Anastasios Brakis, Baylor Knight, Kenny Mitchell, and Tom Williams. Surround haptics: sending shivers down your spine. In *ACM SIGGRAPH 2011 Emerging Technologies*, page 14. ACM, 2011.

[7] Ali Israr, Seung-Chan Kim, Jan Stec, and Ivan Poupyrev. Surround haptics: tactile feedback for immersive gaming experiences. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems*, pages 1087–1090. ACM, 2012.

[8] Ali Israr, Siyan Zhao, Kyna McIntosh, JaeKyun Kang, Zachary Schwemler, Eric Brockmeyer, Mark Baskinger, and Moshe Mahler. Po2: augmented haptics for interactive gameplay. In *ACM SIGGRAPH 2015 Emerging Technologies*, page 21. ACM, 2015.

[9] Pontus Larsson, Daniel Västfjäll, and Mendel Kleiner. Perception of self-motion and presence in auditory virtual environments. In *Proceedings of seventh annual workshop presence*, pages 252–258, 2004.

[10] Bernhard E Riecke, Daniel Feuereissen, and John J Rieser. Auditory self-motion illusions (circular vection) can be facilitated by vibrations and the potential for actual motion. In *Proceedings of the 5th symposium on Applied perception in graphics and visualization*, pages 147–154. ACM, 2008.

[11] Ryuta Okazaki, Taku Hachisu, Michi Sato, Shogo Fukushima, Vincent Hayward, and Hiroyuki Kajimoto. Judged consonance of tactile and auditory frequencies. In *World Haptics Conference (WHC), 2013*, pages 663–666. IEEE, 2013.

[12] Kevin Fan, Hideyuki Izumi, Yuta Sugiura, Kouta Minamizawa, Sohei Wakisaka, Masahiko Inami, Naotaka Fujii, and Susumu Tachi. Reality jockey: lifting the barrier between alternate realities through audio and haptic feedback. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2557–2566. ACM, 2013.

[13] Google VR developer overview - google vr sdk for unity - spatial audio. `https://developers.google.com/vr/concepts/spatial-audio`. Accessed: 2017-02-03.

[14] Oculus audio sdk - oculus native spatializer for unity. `https://developer3.oculus.com/documentation/audiosdk/latest/concepts/book-ospnative-unity/`. Accessed: 2017-02-03.

[15] NEUMANN products - current microphones - ku 100. `https://www.neumann.com/?lang=en&id=current_microphones&cid=ku100_description`. Accessed: 2017-02-03.

[16] Apple logic pro x. `http://www.apple.com/logic-pro/`. Accessed: 2017-02-03.