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Master's Thesis
Academic Year 2015

Tangible Sound:
A Tangible Interface for Object-based Sound Systems

Graduate School of Media Design,
Keio University

Keiko Ogawa

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

Keiko Ogawa

Thesis Committee:

Professor Hideki Sunahara	(Supervisor)
Professor Sam Furukawa	(Co-supervisor)
Professor Masa Inakage	(Co-supervisor)

Abstract of Master's Thesis of Academic Year 2015

Tangible Sound: A Tangible Interface for Object-based Sound Systems

Category: Science / Engineering

Summary

In recent years, due to the development of Information Technology, the Internet Protocol(IP) network is replacing analog lines of audio systems. This enables us to control 3-D sound easily by software. In 2012, Dolby adopted their cinema sound platform "Atmos" to theaters. They adopted object-based method of thinking to the sound system which allows the placement of the sound objects anywhere in the theater virtually. However, most of the object-based sound systems are for professional use. In addition, when we play the sound contents with the speakers, the speakers are normally placed in predefined locations and the contents are also finalized to be played with existing audio systems. Most of the sound systems are only used for the purpose of listening and there are no interaction with the sounds played from the speakers.

In this thesis, the author approached Tangible Sound to lead people to have interactions with the audio systems. With the use of Tangible Sound, user could move and place the sound objects intuitively in real space, also in real-time without any visual interfaces by using the location sensors. It is argued through this research that Tangible Sound took an important step in making it possible to handle a sound object as a physical object by combining the object-based sound and the location information. It is expected that the spatial interactions with the sound may open up a door to an acoustic experience of the future such as "holding" and "throwing" the sound, and we will be able to use sounds as new ways of expression in live entertainment, educational field and so on.

Keywords:

Tangible, Interface, Object-based, Sound, Interaction Design

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Chapter 1
Introduction

In 1881, Clement Ader released “Theatrophone” in the first International Exposition of Electricity in Paris. It was also known as “Stereophonic Sound”, a new method of sound reproduction. It was invented to recreate the sound environment by using phones which allows users to listen to a realistic sound of stage performance 3 km away from the Paris Electrical Exhibition [1]. Since then, there have been many approaches and research in various fields to create realistic sound environments such as surround sound and binaural sound.

In recent years, due to the development of Information Technology, the Internet Protocol(IP) network is replacing analog lines of audio systems. This enables the users to be able to control the 3-D sound easily by software. In 2012, Dolby adopted their cinema sound platform, “Atmos,” to theaters. They brought object-based method of thinking in which the system executes digital signal processing of data of sound objects and makes a decision of volumes and phases from the multitude of speakers installed in theaters [2] [3]. Furthermore, increasing number of professional audio systems are also adopting such networking system and rapidly shift from analog cable to Ethernet cable. This also enables users to recreate the sound environment in many places at the same time with using the IP network.

However, when we play the sound contents with speakers, the speakers are placed in predefined locations and musical contents are finalized to be played with existing audio systems. In other words, most of sound systems are only used for the purpose of listening and there are no interactions with the sounds played from the speakers. In addition, professional skills are required to control the sound.

On the other hand, various studies have been conducted on “Tangible user interface.” It is a user interface which enables users to grasp and to manipulate digital information through the physical objects and materials. Tangible user interface is formulated by Hiroshi Ishii, a professor of MIT Media Laboratory [4]. In addition, many electronic musical devices have been developed which aim to allow people to control sound or play music with their body movement.

However, some of these technologies have remained widely unpopular because of the lack of their accessible interface. Users would need to learn how to control the complex equipment if they would like to control sound or play music freely and intuitively. Also, it is considered that the acoustic experience are often different from our daily experience generated through these systems.

In order to overcome these limitations, it was considered that Tangible Sound should not have any difficult operation or training to use. Also, it should not have any heavy device which users wear or carry so that the user's movements and intuitive experience are not interrupted.

Tangible Sound is a tangible interface which allows users to move and place sounds by user's hand in real space without any visual interfaces such as a screen and light. To experience Tangible Sound, the users need to be in the designated space. Users can move and place sounds by moving and placing the location tags or any physical objects which the location tag is installed. Tangible Sound allows users to imagine the shape, size(volume), location in three dimensions and distance of sound objects.

In this thesis, the pre-experiment and the main experiment were conducted. The pre-experiment exolored how people imagine size(volume), location of the sound object and distance between people and the sound object by listening to the sounds played from the system of Tangible Sound. By using various type of sounds and comparing the characteristics between real sound and virtual sound, the most appropriate sounds to be used in the main experiment were determined.

The main experiment was conducted to explore the actual experience and the usability of Tangible Sound. In the main experiment, the author explored the experience and the usability of Tangible Sound, and also the evaluation of the system of Tangible Sound through trying two examples of using Tangible Sound which was described in chapter 3.2.

In the main experiment, the users could successfully combine the object-based sound and location information. Some participants were reported to have the experience of "holding the sound", by figuring out the shape of the sound for the first time. The users were observed to have the simulated experience of being able to "move" the sound by the hand, and change the imagined location of the source in real time. On the other hand, some problems became clear.

This thesis has proposes Tangible Sound, a tangible interface for object-method sound system. The use of Tangible Sound allows us to renew our perception of the sound which we usually listen to. It is argued through this research that Tangible Sound took an important step in making it possible to handle a sound object as a physical object by combining the object-based sound and location information. It is expected that the spatial interactions with the sound may open up a door to an acoustic experience of the future.

The chapters in this thesis are organized as follows. In Chapter 2, the research background and related work on realistic sound, 3D audio technology, and tangible user interface are described. Chapter 3 describes the approach and concept to achieve the objectives of this study. In Chapter 4, the implementation of the system is described. In Chapter 5, how the system was evaluated, including experiment and its result, is explained, and some imlications are presented in Chapter 6. The last chapter presents the conclusions and directions for further research.

Chapter 2
Related Works

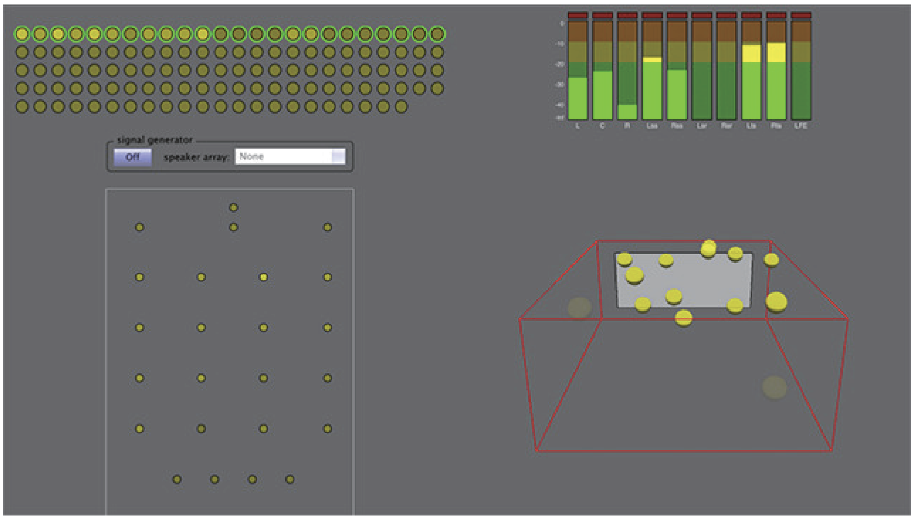
2.1 Realistic Sound, 3D Audio Technology

2.1.1 Dolby Laboratories, Inc.

Dolby Laboratories Inc. is an American company specialized in audio noise reduction, audio encoding and audio compression. They are holding a leading position in sound reproduction in the film industry. Their specialty is the sound reproduction technique that sound field surrounds listener to feel high realistic sensation. Dolby [5] released “Dolby Stereo” in 1975. Dolby [5] states Dolby Stereo as “Encoding four channels of sound down to two channels to record on film, then decoding them back to four channels allowed for stereo in the limited space on film stock.” In 1978, They released “Dolby Stereo 70mm” wich included a noise reduction system. Dolby [6] worked the system slightly for home use and introduced “Dolby Surround 7.1” in 2010, and set up theaters worldwide with 7.1 surround speaker setups to deliver theatrical 7.1 surround sound.

In April 2012, Dolby [5] introduced “Dolby Atmos”, a new cinema sound technology consisting of overhead speakers. This “Dolby Atmos”, Dolby adopted object-based method which let moviemakers place and move sounds anywhere in the theater. This enables filmmakers to create a virtual reality of sound in the middle of the movie action. See figure 2.1, screen of Dolby Atmos Monitor [3]. Dolby [3] explains that “The yellow dots in the lower right represent sound objectsa gunshot or a woman’s scream, for instancethat can be moved around the listening space.” The first generation cinema hardware, the “Dolby Atmos Cinema Processor” supports up to 128 discrete audio tracks and up to 64 unique speaker feeds [7]. In 2014, Dolby Laboratories announced plans to bring Atmos to the home theater industry.

In this research, the object-based method is adopted to achieve Tangible Sound by combining an object-based sound system and a location sensors.



Source: Dolby Lab Notes [3]

Figure 2.1: Screen of Dolby Atmos Monitor

2.1.2 Software Defined Media

Software Defined Media(SDM) Working Group is one of working groups of WIDE Project [8]. Members are from University of Tokyo, Keio University, YAMAHA Cooperation, KDDI R&D Labs., Inc., Panasonic Corporation, Dolby Laboratories, NTT Laboratories and others. In 2014, SDM was founded to aim for creating business by using an audio-visual system which works on the IP network environment and object-based digital media. SDM is a foundational approach which is abstraction and visualization of equipments' functions in order to provide an audio-visual system as a service. To abstract and visualize the lower function of visual and audio allows us to manage the software system and input/output device of audio/visual separately(decoupling). This enables us to manage and construct audio visual system based on the purpose flexibly and intelligently. They have arrived at their conclusion that it is necessary to create object-based digital media which is being able to process the real-time rendering of 3D audio-visual space connected to network, not only with existing channel-based audio-visual system to control and provide visuals and sound environment effectively [9] [10].

The author is one of the members in SDM Working Group. This research was operated as one of research in SDM Working Group.

2.1.3 NHK Science & Technology Research Laboratories

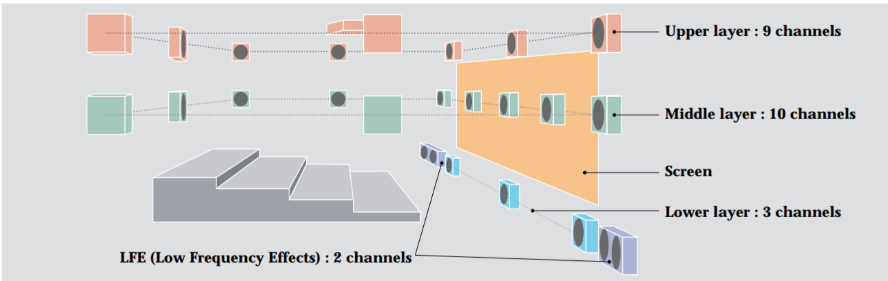
NHK Science and Technical Research Laboratories is a laboratory which is responsible for technical research at Nippon Hoso Kyokai(NHK), Japanese public broadcaster. They developed the world's first HEVC(High-Efficiency Video Coding) encoder for 8K ultra HDTV "Super Hi-Vision" which is 16 times the number of HD pixels and a 22.2 multichannel surround sound experience [11]. Kimio Hamasaki and Koichiro Hiyama(2006) state [12] that

> The main features of the 22.2 multichannel sound system are that the loudspeakers are positioned not only at earheight, but also above and below the viewer. In contrast to conventional theater sound systems, in which loudspeakers are placed only at ear level, with sound coming from the front and rear, and left and right, the sound in the 22.2 multichannel system approaches the listener from above and below as well.

Figure 2.2 is a general illustration of a 22.2 multichannel sound system. The loudspeakers are positioned in layers, at three heights. Kimio Hamasaki and Koichiro Hiyama(2006) describe four features of this system as follows [12]:

1. Matching of sound with on-screen picture
2. Maintaining realism over a wide viewing range
3. Achieving a sense of sound approaching from above or below
4. Ensuring compatibility with current theater sound formats

This development is a one of close approaches to Software Defined Media(SDM).

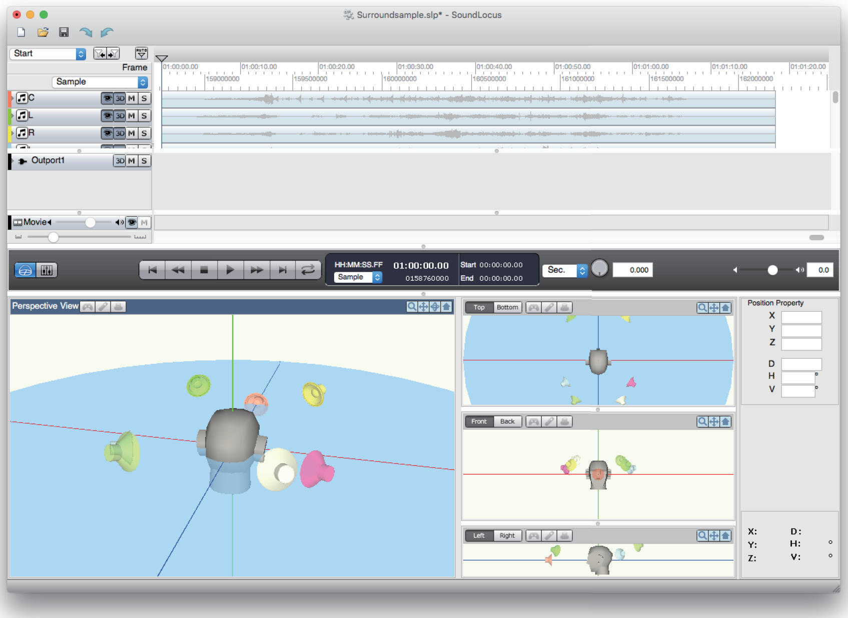


Source: Broadcast Technology, 2006 [12]

Figure 2.2: 22.2 multichannel sound system

2.1.4 Soundlocus

Soundlocus is an authoring tool for creating spatial acoustics contents by ARNIS SOUND TECHNOLOGIES. ARNIS SOUND TECHNOLOGIES states [13] that "SoundLocus is a 3D audio effect processor that can encode mono, stereo, and multi-channel audio to a binaural format, and allows sounds to be freely placed and moved around an acoustic space." SoundLocus digitally processes the audio signal and allows free placement and movement in a 3-D space. By using Soundlocus, it is possible to place pre-recorded sounds in a virtual acoustic space. SoundLocus remedies the traditional problems with binaural recording including the size and cost of binaural recording equipment, as well as minimizing the loss of spatial imaging during mixing [13]. As shown in figure 2.1.4, Soundlocus also adopts the object-based sound method in their software.



Source: ARNIS SOUND TECHNOLOGIES, 2015 [13]

Figure 2.3: Screen of Soundlocus

2.2 Tangible User Interface

2.2.1 musicBottles

musicBottles is a tangible interface developed by Tangible Media Group in MIT Media Lab [14, 15]. Hiroshi Ishii, et al(1999) state [16] that

> It deploys bottles as containers and controls for digital information. The system consists of a specially designed table and three corked bottles that "contain" the sounds of the violin, the cello and the piano in Edouard Lalo's Piano Trio in C Minor, Op. 7. Custom-designed electromagnetic tags embedded in the bottles enable each one to be wirelessly identified. The opening and closing of a bottle is also detected. When a bottle is placed onto the stage area of the table and the cork is removed, the corresponding instrument becomes audible. A pattern of colored light is rear-projected onto the table 's translucent surface to reflect changes in pitch and volume. The interface allows users to structure the experience of the musical composition by physically manipulating the different sound tracks.

Source: MIT Media Lab: Tangible Media Group, 2015 [16]

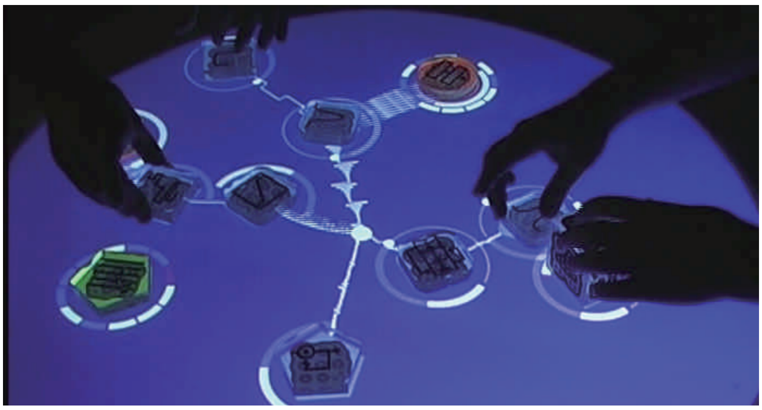
Figure 2.4: musicBottles

2.2.2 REACTABLE

Reactable is an electronic musical instrument with a tabletop Tangible User Interface that has been developed within the Music Technology Group at the Universitat Pompeu Fabra in Barcelona, Spain by Sergi Jord, Marcos Alonso, Martin Kaltenbrunner and Gnter Geiger. The project started in February 2003, with the goal of developing the best computer-based musical instrument without being necessarily constrained by any predefined technology [17].

The Reactable is an electronic musical instrument that enables users to experiment with sound, change its structure and be creative in a engaging, fun and visually appealing way. Sergi Jordà, et al(2007) state [18] that

> The instrument uses a tangible interface where the player controls the system by manipulating real objects. By putting these objects on the Reactable surface, turning them or connecting them to each other, players can combine different elements like synthesisers, effects, samples and control elements in order to create a unique composition. The resulting sonic flows are represented graphically on the table surface, always showing the real waveforms that travel from one object to the other, turning music into something visible and tangible.

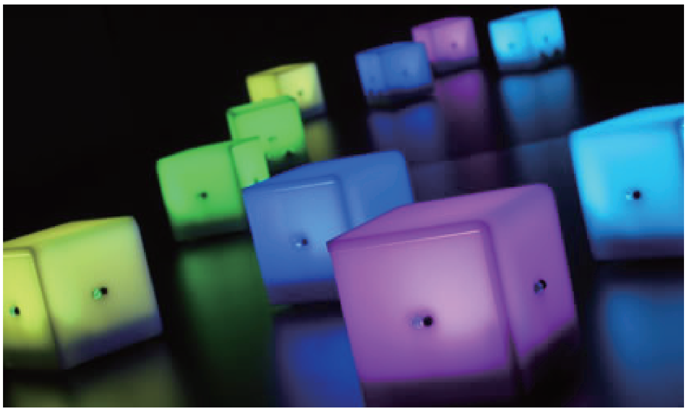


Source: Proceedings of the 1st international conference on Tangible and embedded interaction, 2007 [18]

Figure 2.5: Reactable

2.2.3 AudioCubes

AudioCubes is a tangible user interface developed by Percussa Inc.,. The concept of the AudioCubes was first presented by Bert Schiettecatte in April 2004 at the CHI2004 conference in Vienna [19]. AudioCubes allows any person interested in sound design to explore and create dynamically changing sound. Bert Schiettecatte and Jean Vanderdonckt(2008) state [20] that "A new sound is created by manipulating distributed cube tangible user interface that can be coupled wirelessly by locating them in the interaction range of each other on a table. At any time, a sound processing network combines operational properties of AudioCubes, such as location on a plane or in space, movement, arrangement with other cubes, and layout. Sound algorithm parameters and the configuration of the sound processing network can be changed simultaneously, allowing a fast and convenient exploration of sound creation space that creates a new interaction technique for creating sounds. "



Source: Proceedings of the 2nd international conference on Tangible and embedded interaction, 2008 [20]

Figure 2.6: AudioCubes

2.2.4 TENORI-ON

TENORI-ON is a digital musical instrument designed by Media artist Toshio Iwai and Yamaha Corporation. The interface of TENORI-ON consists of a 16x16 matrix of light emitting switches. TENORI-ON allows everyone to play music intuitively, creating a “visible music” interface [21]. The switches are not just input switches, like the keys on a keyboard, but function as individual displays that emit light that emulates intuitively the related sound. Yu Nishibori and Toshio Iwai(2006) states [22] that “When you push a switch for a short time, a ripple of light spreads out from switch that corresponds with sound you have chosen. If a switch is held down slightly longer, a dot of light remains on the panel indicating that the light and the sound will be played repeatedly. One remarkable effect of this sound and light synergy is that people seem to quickly understand the relationship between the sounds and switches such that even non-musicians can enjoy improvising and even composing almost immediately”.

Source: Proceedings of the 2006 conference on New interfaces for musical expression, 2006 [22]

Figure 2.7: TENORI-ON

2.2.5 Theremin

The theremin is an electronic musical instrument which the performer can control without physical contact. The theremin was invented in 1919 by a Russian physicist named Lev Termen(Leon Theremim). Two antennas protrude from the theremin. One controls pitch, and the other controls volume. As a hand approaches the vertical antenna, the pitch gets higher. Approaching the horizontal antenna makes the volume softer. Theremin World describes [23] that “Because there is no physical contact with the instrument, playing the theremin in a precise melodic way requires practiced skill and keen attention to pitch. The electric signals from the theremin are amplified and sent to a loudspeaker." The theremin was used in movie soundtracks. It has also been used in theme songs for television shows. This has led to its association with a very eerie sound. Theremins are also used in concert music and in popular music genres such as rock [23].

Source: Theremin World, 2005 [23]

Figure 2.8: Theremin

2.2.6 Miburi

The Miburi is a wearable musical instrument developed by the Yamaha Corporation's in 1994 [24]. By wearing the specialized wear and moving with it, the sensor gets the movement and replace the movement to musical scale. The body movement becomes music directly. To play music or rhythm, the player control the specialized wear by their body movements. The Miburi consists of specialized wear which loaded with sensors on shoulder, elbow, wrist and others, grip sensors to play with both hands, and speaker unit [25].

Source: Miburi; Products The 1990s, 2015 [25]

Figure 2.9: Miburi

2.3 Issues from Related Works

In these days, some companies have been adopting the object-based method for managing sound systems. It is considered that visualization and abstraction of the function of audio-visual systems enable us to manage and construct audio visual system based on the purpose flexibly and intelligently. In addition, some companies are working on bringing the object-based sound system to the home theater industry. The software such as Soundlocus had been released for the public to create the sound environment easily, but it is imaginable that the operation of placing the sound object by using 2-D display is very hard to control and understand for general people. In fact, most of the object-sound systems and latest sound systems which can create a 3-D sound environment are professional use. The object-based sound system enabled us to create a 3-D sound environment effectively, but there are no interaction between the sound and listeners. Most of sound systems, the speakers are in predefined locations and the sound contents are also finalized.

On the other hand, there have been conducting many researches in the field of tangible user interface and also, there have been developed many electronic musical devices which aim to let people control sound or play music with users movement or gesture. However, some of them have not been big hits because of their usability. Users needed to understand and practice if they would like to control sound or play music freely and intuitively. It is considered that the experience of them are often different from our daily experience of grasp and manipulation.

From these issues, it was considered that Tangible Sound should not have any difficult operation. Here are the required items to design and achieve Tangible Sound.

- Tangible Sound needs the designated empty space
- Tangible Sound should not have any difficult operation
- Operations should be sensuous and have relations with our daily operation
- Tangible Sound should work in real-time
- The device should not disturb users operation

Chapter 3

Tangible Sound: A Tangible Interface for Object-based Sound Systems

3.1 Basic Idea

Tangible Sound is a tangible interface which allows users to move and place sounds by our hand in real space without any visual interfaces such as a screen and light. Basically, sound is invisible and it is impossible to touch. The aim of this study is to make it possible to touch sound by touching physical objects. To achieve this, the idea of connecting the object-based sound and 3-D location information is adopted. As a result of this, it is expected that Tangible Sound allows users to imagine shape, size(volume), location in three dimensions and distance of sound objects. The system of Tangible Sound consists of a sound system which includes 8 speakers to play 3-D sound based on the object-based method and location sensors and tags to get the 3-D location information in real time. Detailed description will be given in chapter 4. As a result of this, it is considered that users will be able to move and place sounds by their hands and movements in real space, also in real time. As a result of this, users will be able to "throw" the sound, or we could recreate an actual sound environment anywhere in real-time.

3.2 User Interface

To experience Tangible Sound, users need to be in the designated space. Users can move and place sounds by moving and placing the location tags or any physical objects which the location tags are installed.

Here are two examples of using Tangible Sound.

To add any sound to any location in the space:

1. Select the sound which user want to play from the library
2. Sound will play at the location of the tag or the physical object
3. Grab the tag or the physical object and move it to any location
4. Place the tag or the physical object

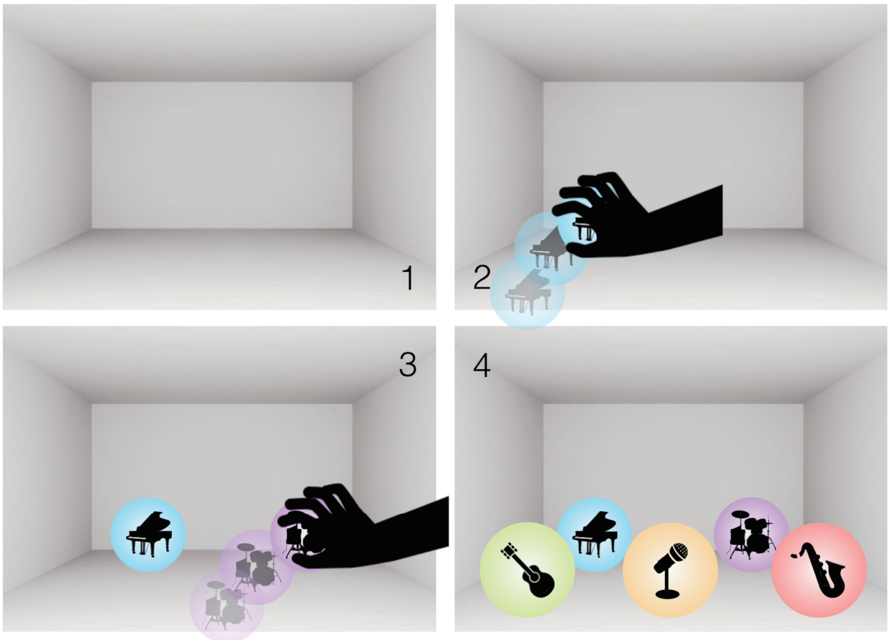


Figure 3.1: To add any sound to any location in the space

To move the sound which is already played to any location in the space:

1. Find the sound which user want to move in the space
2. Grab the sound(the tag or the physical object)
3. Move the sound(the tag or the physical object) to any place
4. Place the sound(the tag or the physical object)

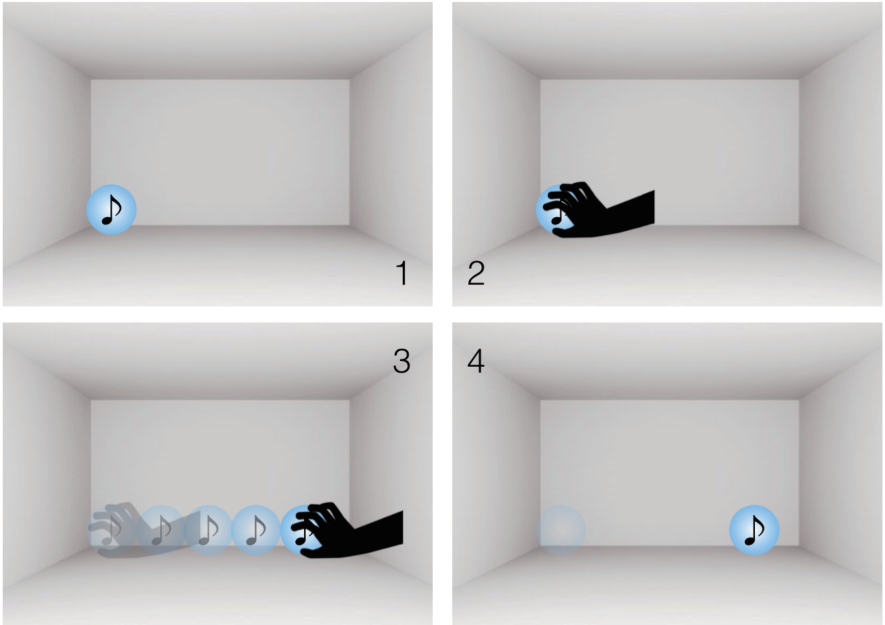


Figure 3.2: To move the sound played in the space

As can be seen from examples of Tangible Sound, it allows users to handle the sounds as physical objects in real space. Figure 3.3 shows that a user actually placing sounds as physical objects in the designated space.

Figure 3.3: User placing sounds as physical objects

3.3 System Operation

The system operation of the Tangible Sound is shown in Figure 3.4 and Figure 3.5. Here is the brief explanation of the system operation:

1. Prepare a space in real space and a virtual space of the space in real space
2. Install the location sensors on four corners in real space
3. The sensors get the position of the tag which user holds, then the location information(x,y,z) will send to the virtual space and appear as an object (Figure 3.6)
4. Set any sound on the object(the location of the tag)
5. The sound will be playing from the location of the tag
6. Since the sensors get the location of the tag continuously, the user can move and place the sound in the real space

Detailed description of the system and its components will be given in chapter 4.

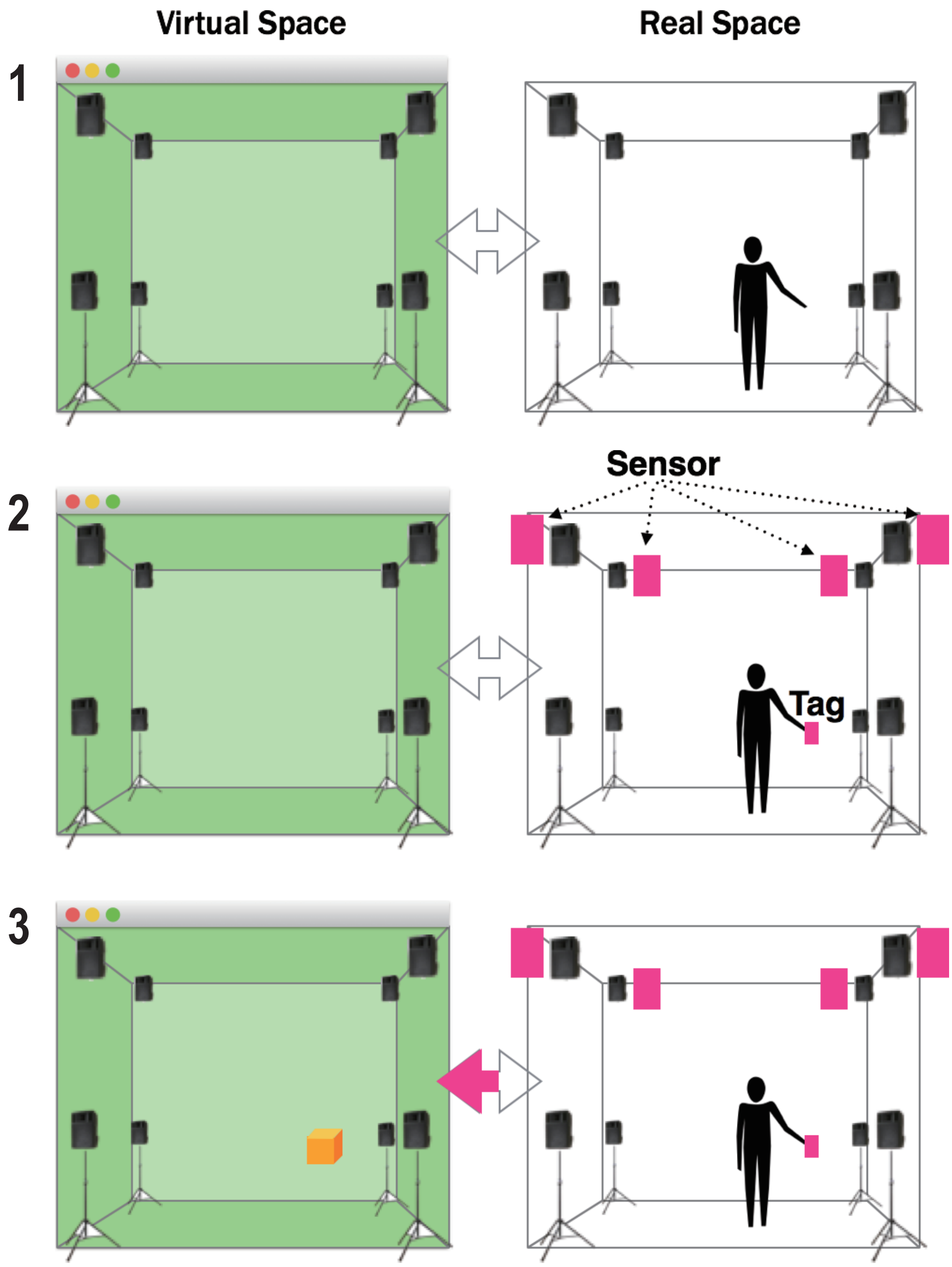


Figure 3.4: System Operation 1

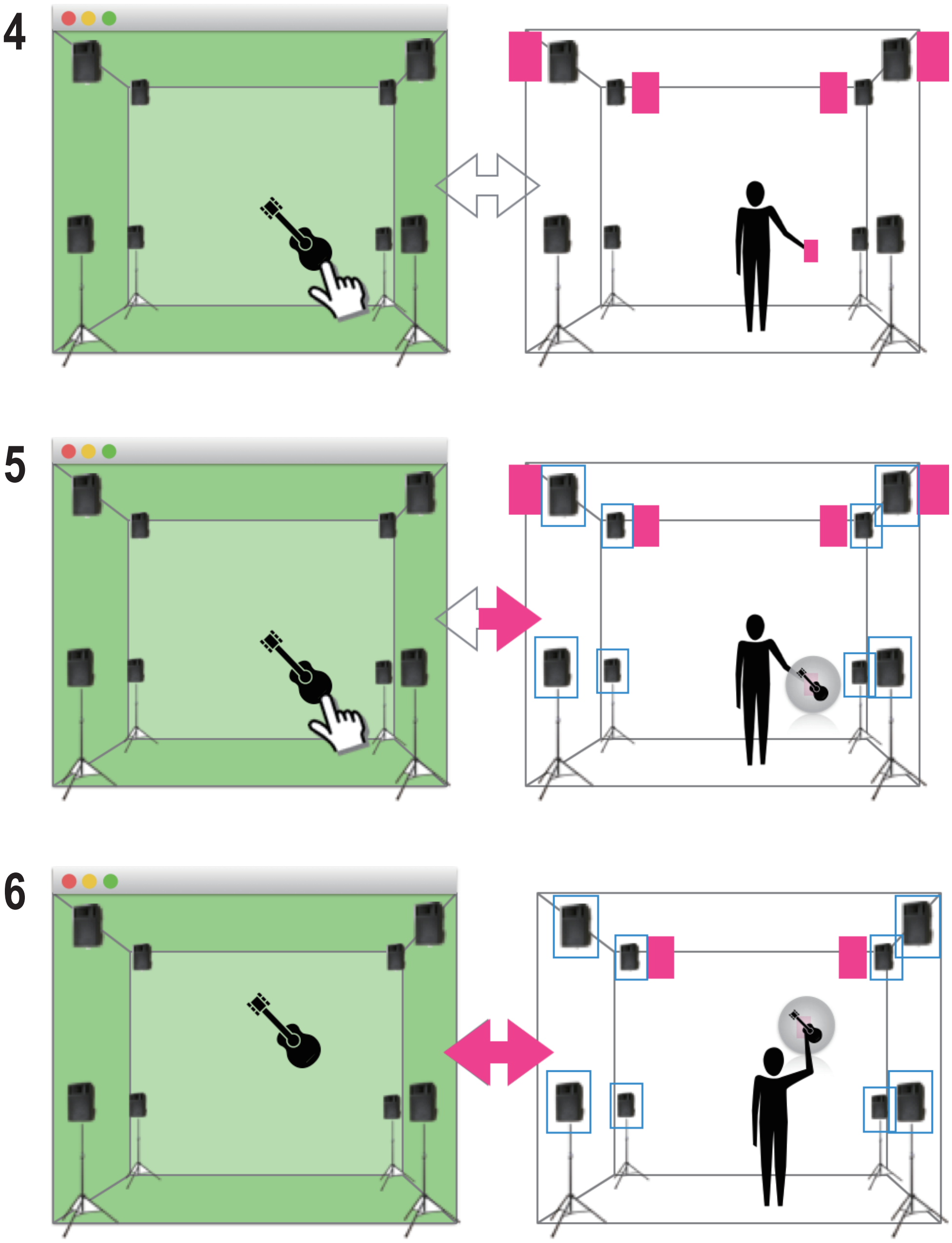


Figure 3.5: System Operation 2

Figure 3.6: The location information appears as an object in the virtual space

Chapter 4
System Implementation

4.1 System Implementation

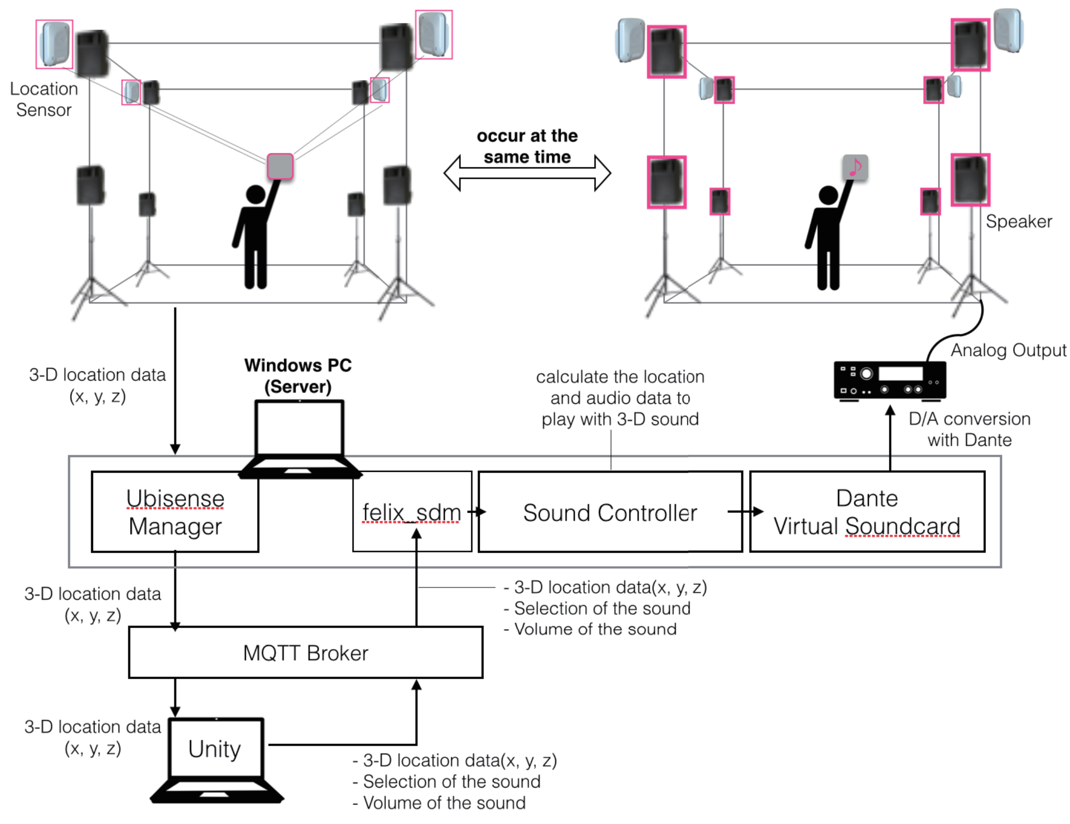


Figure 4.1: System Implementation

As illustrated in Figure 4.1, in order to make 3D sound tangible, receiving the location data and playing the sound should occur at the same time. The location data of the tag which the user is holding is received by 4 location sensors which set in the space. Sensors are managed by the software which installed in the computer, and the computer sends the 3D location data to the MQTT Broker. By using unity, get the location data from the MQTT Broker and import to Unity. At this time, the object is moving as the same position as the tag. Unity send the location data and selection of the sound to MQTT broker. Then, felix_midi is going to get them from MQTT Broker and send them to VSSS by using LoopMIDI. VSSS is going to calculate the location and audio data to play with 3-D audio. VSSS sends the data to Dante Virtual Soundcard and it converts the sound data to analog signal based on the calculation. The sound will be played from the speakers so that it matches to the location of the tag which the user holding.

To approach this research, the whole system was set in a room and the 3D modeling data of the room was prepared in the Unity. See Figure 4.2 and 4.3, respectively.

Figure 4.2: Set the system in the room

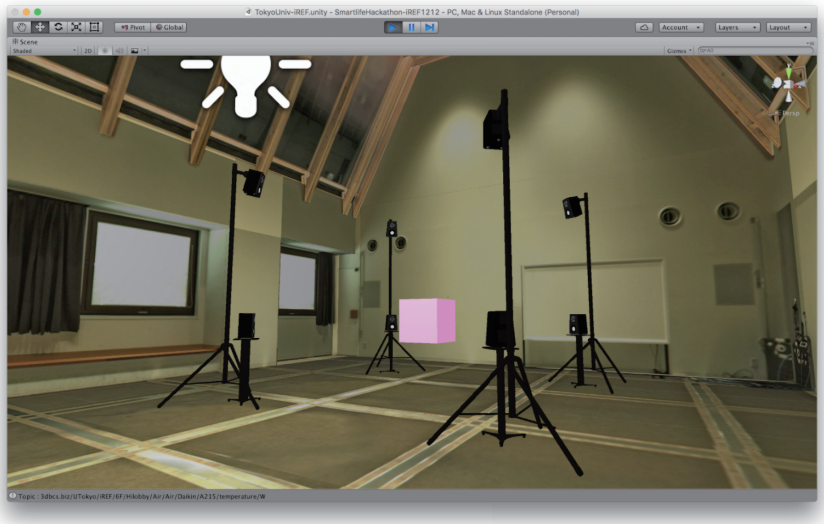


Figure 4.3: Screen of Unity: Modeling of the Room

4.2 Components

Tangible Sound mainly consists of 8 speakers, Yamaha Amplifier XMV8280-D, Ubisense system with 4 location sensors and tags, MQTT Broker and PC with Windows 8 OS which Virtual Soundscape System(VSSS), Dante Virtual Soundcard, LoopMIDI and Ubisense Manager are installed in.

8 Speakers

Tangible Sound uses 8 speakers to create 3-D sound in the space. Speakers are YAMAHA NS-B500.

Yamaha Amplifier XMV8280-D

Tangible Sound uses Yamaha Amplifier XMV8280-D to output the sound from speakers. The amplifier is compatible with Dante Network.

Ubisense System

Tangible Sound uses Ubisense system. The system gathers up the location data of tags from the sensors by using UWB wireless signal. When the system is running, the sensors receive the location data up to 40 times per second. The system consists of 4 Location Sensors and tags to get the location of user's hand and their movement. Users can manage the whole systems from any computers which have company's software are installed [26]. The screen of Ubisense Manager shows the trajectory of 3 tags is shown in Figure 4.4.

Figure 4.4: Tags of Ubisense

Source: Ubisense: Real-time location at a glance , 2016 [27]

Figure 4.5: Sensor of Ubisense

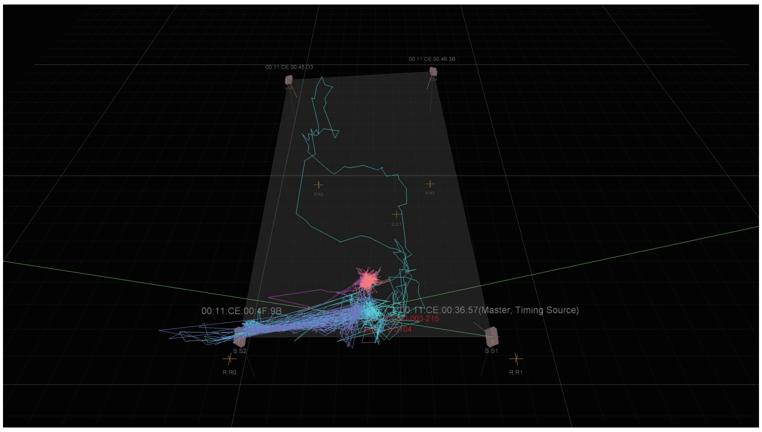


Figure 4.6: Ubisense: Screen of Ubisense Manager shows the trajectory of 3 tags

felix_SDM

felix_SDM is a software developed by SDM WG in order to exchange MIDI file and location data between MQTT Broker and VSSS.

loopMIDI

loopMIDI is virtual loopback MIDI cable for Windows XP up to Windows 10, 32 and 64 bit. This software can be used to create virtual loopback MIDI-ports to interconnect applications on Windows that want to open hardware-MIDIports for communication. The ports created are unique for each user and only exist while the loopMIDIapplication is running [28]. In Tangible Sound, loopMIDI is used for exchanging MIDI file between felix_midi and VSSS.

Virtual Soundscape System(VSSS)

Virtual Soundscape System(VSSS) is the audio control system to recreate and experience the latest sound production for events or facilities. The system is developed by Bandai Namco Studio and the system is also an application which works on Windows. The system is actually in the use of games of Bandai Namco Games and it offers an interactive technology which responses in real-time to the players' operation [9]. In Tangible Sound, VSSS calculates the location and audio data and send to Dante to play from the 8 speakers.

Dante(Dante Virtual Soundcard)

Dante is an audio network developed by Audinate. By using Dante network, users can send and receive numbers of channel of uncompressed audio with low latency. Also, Dante corresponds with Ethernet and the IP network. Dante doesn't need any dedicated network infrastructure. Users can deal with everything from signals of Dante to other signals of lighting or projection at the same time. Therefore it is available to merge existing network into Dante network [29] [30]. In Tangible Sound, Dante will output the sound from 8 speakers which was calculated by VSSS. The sound data which will play as Tangible Sound are prepared here.

Unity

Unity is a cross-platform game engine developed by Unity Technologies and used to develop video games for PC, consoles, mobile devices and websites [31]. In Tangible Sound, the author recreate the virtual space in Unity and import the location data from Ubisense tag to the virtual Space. Also, to play the sound from speakers, the author uses Unity to send location data and channel of the sound to VSSS. The screen of Unity shows a 3-D object appeals at the location of the tag is shown in Figure 4.7.

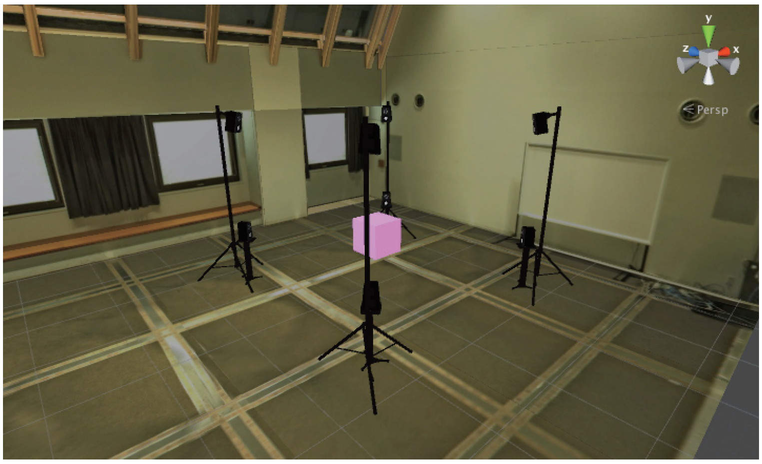


Figure 4.7: Screen of Unity: A 3-D object appeals at the location of the tag

MQTT Broker

MQ Telemetry Transport(MQTT) is a publish-subscribe based “light weight” messaging protocol for use on top of the TCP/IP protocol. To exchange message, MQTT needs MQTT Broker which is a server to relay messages. In Tangible Sound, location data, selection of the sound and volume are exchanged by using MQTT Broker.

Chapter 5
Experiment

This thesis aims to study the experience of Tangible Sound. As described in chapter 3, Tangible Sound aims that to make it possible to touch sound by touching physical objects. In this chapter, the author explored how users feel and experience the 3-D sound which played from the system of Tangible Sound as pre-experiment. From the result of pre-experiment, the main experiment was conducted to study the experience and usabilities of Tangible Sound when users actually use Tangible Sound.

5.1 Pre-Experiment: Experience of 3-D sound

5.1.1 Purpose

The pre-experiment was conducted in order to study the reproducibility of 3-D sound played from the system of Tangible Sound. In the pre-experiment, how users imagine size(volume), location of the sound object and distance between users and the sound object by listening to the sounds played from the system of Tangible Sound was explored. The author focused on following points for the sounds: type, length of sound, actual size of sound object, actual height of sound object, and sound format. There were some sounds which don't have height expression. By using various type of the sounds and comparing the characteristics between real sound and virtual sound, the most appropriate sounds for Tangible Sound came out and used in the main experiment.

5.1.2 Settings

Answers from 12 participants were collected. The pre-experiment was took place in a lecture room "Hilobby" in University of Tokyo and all the systems were set as the same as described in chapter 4. To conduct the experiment, each participant needed to be at the center of the designated space surrounded by speakers. Each participant was assigned to answer and comment to their experience using a worksheet with questions after listened to 3-D sound played by the system of Tangible Sound. The sound used in the experiment is described in Table 5.1.

Table 5.1: Types of Sounds

No.	Type	Name	Length	Size	Height	Format	Height Expression
1	Effect	Mosquito	continuous	2cm	-	midi	YES
2	Effect	Dog	3sec	1m	30cm	midi	NO
3	Effect	Robot(footstep)	continuous	10m	-	midi	NO
4	Effect	Voice(speak)	5sec	150cm	150cm	midi	NO
5	Effect	Firework	4sec	60m	100m	midi	YES
6	Effect	Cheer	6sec	-	-	midi	Height Only
7	Effect	Rain	continuous	-	-	midi	Height Only
8	Music	Female Voice(song)	3min	-	171cm	wav(recorded)	YES
9	Music	Piano	3min	-	100cm	wav(recorded)	YES

All the sounds were played more than twice, first time, the sounds were staying, and second time, the sounds were moving from somewhere to somewhere. The sounds played in random order and the location of sounds were also in random location. The sound, the location and movement was controlled from the Unity.

The questions were as follows:

1. What was the sound you heard?
2. Was the size of the sound(object) clear or unclear? If clear, how big was it?
3. Was the height of the sound clear or unclear? If clear, how height was it?
4. Where was the location of the sound(object)?(right, left, front, back...)
5. Could you follow the track of sound movement?(rate on a scale of 1 to 10)

5.1.3 Results

Table 5.2 shows average results for each sounds and some comments for each sounds are as follows. All the results and the comments are attached on the appendix A.

Table 5.2: Result of Pre-Experiment

No.	Name	Q1	Q2	Q3	Q4	Q5
1	Mosquito	Correct	Unclear	Unclear	70%	6
2	Dog	Correct	1m	Unclear	70%	3
3	Robot(footstep)	Correct	10m	10m	80%	8
4	Voice(speak)	Correct	Unclear(big)	Unclear	50%	2
5	Firework	Correct	60m	100m(moving)	80%	8
6	Cheer	Correct	-	10m	-	-
7	Rain	Correct	-	-	-	-
8	Voice(song)	Correct	160cm	160cm	90%	7
9	Piano	Correct	100cm	100cm	80%	6

1. Mosquito
   - Mosquito was obvious when the sound come closer, but it sounded like a very big or a lot of numbers of mosquitoes even if the volume changes.
2. Dog
   - I don't know if the sound itself is the sound that the dog barks in the distance, when the sound come closer, it sounded like it still barks in the distance.
3. Robot
   - The sound of robots made me feel like it was actually moving.
   - It sounded like a big robot.
4. Voice(speak)

  - Voice(speak) felt like someone who is very big like a giant talked to me.(The volume was too loud?)

5. Firework
  - It sounded like a real firework, because of the expression of height.
  - It was interesting that the sound of explosion sounded upper than the speakers.
6. Cheer
  - It sounded like I was in the real cheer. Hearing cheer from above was a new experience. Perhaps the player(soccer) could hear like that.
7. Rain
  - It sounded like I was in the real rain.
8. Female Voice(vocal)
  - It was easy to understand where the vocal locates because of the quality of recording?
9. Piano
  - The sound of piano sounds like I was in the room with a piano.

Here are some feedbacks from the experiment:

- When the sounds move, the sounds which were not continuous were hard to follow.
- It felt like difficult to imagine the sound object when the sound has reverb.
- The surrounded sound like cheer and rain was difficult to imagine the location(height) but it could use for making sound environment or as sound interior.
- There was a difference between sounds that move (footsteps) and sounds that do not move (rain)
- If it's possible to move the sound of rain, cheer, it would be a new experience to move environmental sound. It would be fun to move the sound which we cannot move in daily life.

5.1.4 Summary

Here are the result summary from several points of view.

Sound Type

Each sound are very clear to recognize for most of the participants but, it was seen that there were problems in the way of expression. ex) volume, reverb and quality

Length of Sound

The sounds which were not continuous were hard to follow when the sounds were moving especially the sound of dog, voice(speak) except the sound of firework. The length of firework sound was not so long, but the sound was moving from the ground to the air(long distance) in few seconds continuously, which sounded very clear to the participants. And the sound of female voice was also good to follow the movements, but except the gaps between the phrases of songs.

Size of Sound

The sounds which are basically small or single object such as the sound of mosquito, dog or robot are unclear when the user listened from the system of Tangible Sound. Most of them sounded bigger than the original sizes. The sound of voice(speak) sounds very clear, but it was very hard to recognize it as the voice from actual people. The sound which are basically big, surrounding and extensive such as the sound of firework, cheer or rain are very clear and real when users listened from the system.

Height of Sound

The sound of firework was most suitable for expressing height and it is considered that it is imaginable because the original sounds are also have height. Other sounds which have height expression such as mosquito, cheer, female voice(song) and piano sounded interesting when they go up and down because we don't have such sounds in real life.

Sound Format(Quality)

The sound of female vocal(song) and piano were very clear and real when they played from the system than other sounds. They were actually recorded in high quality.

Surrounded Sound

Surrounded sound such as cheer and rain sounded real but they were not suitable to move around the space. It is consider that it is suitable for environmental sound or combining with other sounds.

Location and Distance of Sound

Some sounds such as surrounded sounds or the sound which is moving were hard to recognize where the sounds were. Other sounds were recognizable roughly especially when they were staying at a certain location. The location where most of participants could recognize were at front, behind, right, left, diagonally in front and diagonally backward. To recognize the location at above and below, it was needed to compare. For example, if you want to hear the sound from above, it is needed to listen to the sound at the below before listening the sound from above. It was possible to follow the sound which moved from somewhere to somewhere roughly.

From the results, it is concluded that the sounds which are continuous, not surrounded or extensive are suitable for Tangible Sound.

5.2 Main Experiment: Experience of Tangible Sound

5.2.1 Purpose

The main experiment was conducted in order to explore the actual experience and the usability of Tangible Sound. As written in chapter 3, Tangible Sound aims that to make it possible to touch sound by touching physical objects. In the main experiment, the author explored the experience and the usability of Tangible Sound, and also the evaluation of the system of Tangible Sound through trying two examples of using Tangible Sound which was described in chapter 3.2.

5.2.2 Settings

Answers from 12 participants were collected. The main experiment was took place in a lecture room “Hilobby” in University of Tokyo and all the systems were set as the same as described in chapter 4. To conduct the experiment, each participant needed to be in the designated space surrounded by speakers. Each participant was assigned to rate the evaluation items(on a scale of 1 to 10) and give feedbacks after experienced Tangible Sound. The participants tried two examples of using Tangible Sound which are:

- To add any sound to any location in the space
- To move the sound which is already played to any location in the space

It was possible to play any sounds and up to two sounds at the same time in the space. The participants used the tags to control the location of the sound. Unity and THS was used for deciding the sound the participants wanted to play with Tangible Sound.

The evaluation items were as follows:

1. How was the quality of sound? (noise, interruption)
2. Real-time operation(when the participants move the sound)
3. How was the quality of location?
4. Could you follow the movement of sound? (ex, when throwing the sound)
5. Did you have the image that you were controlling the sound object?

5.2.3 Result

Table 5.3 shows average results for each items and some categorized feedbacks of the experience of Tangible Sound are as follows. All the results and the feedbacks are attached on the appendix A.

Table 5.3: Average Rating of Evaluation

Evaluation Item	Avarage Rate	Max Rate	Min Rate
Item 1	7.6	10	4
Item 2	8.4	10	5
Item 3	8	10	6
Item 4	8.4	10	5
Item 5	7.8	10	2

Feedbacks about the experience of Tangible Sound:

- I felt a bit bother to move myself to place the sound in the space.
- If used at live/concerts, it would be exciting and a totally new experience for the audience to have sounds moving backward, forward, rightward, and leftward.
- It was my first time “holding” a sound. I played catch with sounds.
- If it’s possible to move the sound of rain, cheer, it would be a new experience to move environmental sound. It would be fun to move the sound which we cannot move in daily life.
- I saw a sound take shape. What does it mean to hold something when it is not visible?
- Hearing cheer from above was a new experience.
- I thought “Real-time” was key point of this research. It is important that we can experience the sound in real-time because the price goes free when the music got digitized
- It was not the experience of seeing the sound object, but I could imagine the sound object.

Feedbacks about the usability of Tangible Sound:

- It would be fun if used in large spaces. I thought interesting shows could be made at theaters/movie theaters by implementing this system using drones.
- If used at live/concerts by flying the tags with balloons, it would become interesting hearing sounds from above.
- This may be useful in simulating certain experiences. (Re-create a situation)
- This would enable people who are unable to leave home, to feel the outside world.
- A harmony of live sounds and finished sounds could be created at live/concerts. Unite with the audience.
- If utilized for online lectures, students will feel less lonely, enjoy the lecture, and concentrate more on the material.
- It may be utilized in remote medical treatment
- Could be used at haunted houses by having the sound approach you as the ghost gets closer.
- The surrounded sound like cheer and rain was difficult to imagine the location(height) but it could use for making sound environment or as sound interior.
- Could be used for a public viewing of sports, but it would be nice if this system could make minor sports popular.
- Could be used for arts. This way of expression is very interesting.

Feedbacks about the system of Tangible Sound:

- It seemed difficult to move this system to high places, so if there are any ways to make this process easier, this project would become much more useful.
- It would have been better if the quality of sound were consistent for all materials.

- Most of times sound played in real time but sometimes it was late(around 1 sec).
- Having more speakers will improve the resolution of the moving sound and position.
- I recognized the sound was going far away, but the volume changed too fast.
- It was difficult to imagine when the sound object overlaps to the user.
- It would be great if we could choose sound from the smartphone or any easy way
- Sometimes the tag didn't work because the obstacle interrupt the wireless signal between the sensors and the tag

Chapter 6
Discussions and Conclusion

6.1 Discussions

Here are the discussion of the main experiment from three points of view.

The experience of Tangible Sound:

In the main experiment, it is considered that the author could combine the object-based sound and location information successfully. Some participants got the experience of “holding the sound”, imagined the sound got shape for the first time. Also, since Tangible Sound operates in real-time, new expressions were occured: move sounds forward and backward in real-time, move sounds which we cannot move in daily life. It could be a new ways of expression. In addition, the further updates are expected: playing many sounds at the same time, adding the features of changing the direction of sound, changing the size of the sound objects, adding effects on each sound object, an interface for choosing any sound, adding sound effects to change the largeness of the space intuitively and so on. On the other hand, some problems became clear. There are some problems in the direction of creating the 3-D sound. It is difficult to recognize the distance of the sound when the sound object laps over the user and go away to the outside of the designated space. Also it is difficult to create the sound object very clear. It is needed the system adjustment of expressing sound in detail by comparing difference between real and virtual.

The usability of Tangible Sound:

By being able to touch the sound object, Tangible Sound is expected to be used for many opportunity. Especially, there are many possibilities in entertainment field. It could be used at the situation of live concert, theater, movie theater, haunted house, museum, sports, art and so on. Also it is expected to use for recreation a situation. Remote conference, remote medical treatment, online lectures are the possible situations. How to utilize the "real-time" feature of Tangible Sound is going to the key point of Tangible Sound.

The system issues of Tangible Sound:

The development of the system enabled us to experience of touching sound, but there are still some issues to be solved. Now the system has the issues which generates latencies at some points and they made a negative experience. There is the problems with the sensors and tags. If the tag get behind from the sensors, the interruption of the signal will occur and Tangible Sound won't operate correctly. If used in large space or in a different environment, it will be needed to redevelop the system and there will be the necessity of selecting tools which are suitable for the situation.

6.2 Conclusion

In conclusion, this thesis has proposed Tangible Sound, a tangible interface for object-method sound system. Basically, sound is invisible and it is impossible to touch. We recognize "sound" as a sound which we can hear with our ear and usually sounds generate from speakers, earphones, musical instruments, daily actions or any environmental actions. The use of Tangible Sound allows us to renew our perception of the sound which we usually listen to. It is argued through this research that Tangible Sound took an important step in making it possible to handle a sound object as a physical object by combining the object-based sound and location information. Users came to be able to move and place sounds by their hand and movement in real space, also in real-time, without any visual interfaces. It is expected that the spatial interactions with the sound may open up a door to an acoustic experience of the future such as "holding the sound", "throwing the sound" and "floating sound", and we will be able to use sounds as new ways of expression in live entertainment, educational field and so on.

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Appendix

A The Result and the Feedbacks

Participant No.1 Unemployed, Male, Age 24

- Evaluation Result

Table A.1: Rating of Evaluation: Participant No.1

Evaluation Item	Rating
Item 1	8
Item 2	10
Item 3	8
Item 4	8
Item 5	8

- It would be fun if used in large spaces. I thought interesting shows could be made at theaters/movie theaters by implementing this system using drones.
- On the other hand, I felt a bit bother to move myself to place the sound in the space.
- It seemed difficult to move this system to high places, so if there are any ways to make this process easier, this project would become much more useful.
- If used at live/concerts by flying the tags with balloons, it would become interesting hearing sounds from above.

Participant No.2 Student and Singer-songwriter, Female, Age 19

- Evaluation Result

Table A.2: Rating of Evaluation: Participant No.3

Evaluation Item	Rating
Item 1	9
Item 2	9
Item 3	10
Item 4	10
Item 5	10

- The sound of fireworks, bugs, and robots made me feel like it was actually moving.
- It sounded like a real firework, because of the expression of height.
- If used at live/concerts, it would be exciting and a totally new experience for the audience to have sounds moving backward, forward, rightward, and leftward.
- This may be useful in simulating certain experiences. (Re-create a situation) I feel excited to imagine how further research on this would enable people to experience the feeling of touching sounds.

Participant No.3 Sound Stylist(Company Employee), Female, Age 25

- Evaluation Result

Table A.3: Rating of Evaluation: Participant No.3

Evaluation Item	Rating
Item 1	8
Item 2	10
Item 3	8
Item 4	9
Item 5	9

- This would enable people who are unable to leave home, to feel the outside world.
- It was my first time “holding” a sound. I played catch with sounds.

- There was a difference between sounds that move (footsteps) and sounds that don 't move (rain)
- If it's possible to move the sound of rain, cheer, it would be a new experience to move environmental sound. It would be fun to move the sound which we cannot move in daily life.
- The purpose of movement, and presence of sounds differs for each sound material.
- I saw a sound take shape. What does it mean to hold something when it is not visible?

Participant No.4 Company Employee, Male, Age 24

- Evaluation Result

Table A.4: Rating of Evaluation: Participant No.4

Evaluation Item	Rating
Item 1	7
Item 2	10
Item 3	7
Item 4	10
Item 5	10

- To play a survival game with this system (personal)
- A harmony of live sounds and finished sounds could be created at live/concerts.
- Unite with the audience
- It sounded like I was in the real cheer. Hearing cheer from above was a new experience. Perhaps the player(soccer) could hear like that.
- It was not the experience of seeing the sound object, but I could imagine the sound object.

Participant No.5 Photographer, Female, Age 24

- Evaluation Result

Table A.5: Rating of Evaluation: Participant No.5

Evaluation Item	Rating
Item 1	6
Item 2	9
Item 3	8
Item 4	9
Item 5	2

- It would have been better if the quality of sound were consistent for all materials.
- It was easy listening to a single sound. However, it was difficult to listen to music in which the orchestra and vocal was separated. Because the whole concept was to make people imagine using sounds. It might be better to combine visuals with this technology rather than combining it with live sounds. If used as music, it needs to be effectively used.

Participant No.6 Flower Arrangement Retail Business, Male, Age 25

- Evaluation Result

Table A.6: Rating of Evaluation: Participant No.6

Evaluation Item	Rating
Item 1	7
Item 2	8
Item 3	10
Item 4	10
Item 5	10

- The sound of piano sounds like I was in the room with a piano.
- May be utilized to organize flower auctions.
- It sounded like a big robot.

Participant No.7 Student, Female, Age 25

- Evaluation Result

Table A.7: Rating of Evaluation: Participant No.7

Evaluation Item	Rating
Item 1	6
Item 2	7
Item 3	6
Item 4	7
Item 5	7

- Mosquito was obvious when the sound come closer, but it sounded like a very big or a lot of numbers of mosquitoes even if the volume changes.
- Voice(speak) felt like someone who is very big like a giant talked to me.(The volume was too loud?)
- It was easy to understand where the vocal locates because of the quality of recording?
- Most of times sound played in real time but sometimes it was late(around 1 sec).
- Sometimes the tag didn't work because the obstacle interrupt the wireless signal between the sensors and the tag

Participant No.8 Company Employee, Male, Age 26

- Evaluation Result

Table A.8: Rating of Evaluation: Participant No.8

Evaluation Item	Rating
Item 1	10
Item 2	9
Item 3	10
Item 4	10
Item 5	10

- It was interesting that the sound of explosion sounded upper than the speakers.

- If utilized for online lectures, students will feel less lonely, enjoy the lecture, and concentrate more on the material.
- It may be utilized in remote medical treatment, so that the doctor will gain more realistic information in addition to treatment scene videos.

Participant No.9 Student, Female, Age 23

- Evaluation Result

Table A.9: Rating of Evaluation: Participant No.9

Evaluation Item	Rating
Item 1	8
Item 2	6
Item 3	9
Item 4	9
Item 5	4

- I don't know if the sound itself is the sound that the dog barks in the distance, when the sound come closer, it sounded like it still barks in the distance.
- It was a little bit unclear how the person needs to move in order to move the sound.
- Could be used at haunted houses by having the sound approach you as the ghost gets closer.
- It would be great if we could choose sound from the smartphone or any easy way

Participant No.10 Student, Male, Age 28

- Evaluation Result
- It felt like difficult to imagine the sound object when the sound has reverb.
- Having more speakers will improve the resolution of the moving sound and position.
- The Z axis was difficult to detect

Table A.10: Rating of Evaluation: Participant No.10

Evaluation Item	Rating
Item 1	9
Item 2	5
Item 3	6
Item 4	7
Item 5	8

- It is a great idea that can be applied in many situations, for example: Art Exhibition, Museum, Theater(like "Sleep No More"), Sport (Tennis ball amplifies, soccer/basketball), Interior Design(Environmental Sounds, birds, waterfall etc.)
- The surrounded sound like cheer and rain was difficult to imagine the location(height) but it could use for making sound environment or as sound interior.

Participant No.11 Composer, Male, Age 27

- Evaluation Result

Table A.11: Rating of Evaluation: Participant No.11

Evaluation Item	Rating
Item 1	9
Item 2	9
Item 3	8
Item 4	7
Item 5	9

- I thought "Real-time" was key point of this research. It is important that we can experience the sound in real-time because the price goes free when the music got digitized
- Could be used for a public viewing of sports, but it would be nice if this system could make minor sports popular.
- Could be used for arts. This way of expression is very interesting.

Participant No.12 Female, Age 53

- Evaluation Result

Table A.12: Rating of Evaluation: Participant No.12

Evaluation Item	Rating
Item 1	4
Item 2	9
Item 3	7
Item 4	5
Item 5	7

- I could feel the sound moving around the room.
- It sounded clear when the sound came closer from far, but it wasn't clear when the sound is very close to myself.
- When the sound stops, I recognized clearly where the sound was.
- I recognized the sound was going far away, but the volume changed too fast.
- It was difficult to imagine when the sound object overlaps to the user.