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Transcending Boundaries: Unleashing Musical Expression through Immersive Sound Image and Reverberation Control System

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This study investigates the potential of immersive sound systems as novel tools for musical expression in classical string quartet performances. Collaborating with composer Uhm SiHyun, a new music piece was designed, incorporating two spatial audio technologies: spatial reverberation and sound image control. The composition focused on enhancing user experiences of the piece, emphasizing the narrative depiction of changes in time and place within the music. A live concert demonstrated the system's effectiveness in enhancing musical experiences. Overall, this research sheds light on the possibilities of immersive sound systems as a new, creative tool for new music composition.

1 Introduction

In recent years, there has been a growing interest in immersive sound systems, and their use has expanded beyond research environments to include sound control for live events, concerts, and performances [1]. Currently, these systems are primarily utilized to create a heightened sense of presence and enhance the audience's immersion in the content. If these systems can assist in enhancing perceived presence and immersion, it is reasonable to presume that they could also impact content creators.

Therefore, instead of viewing immersive sound systems as extensions of conventional electrical acoustic systems (that could not actively interact with the content), we propose a novel idea: these systems can serve as new tools to expand the artistic creativity and productivity of content creators. We hypothesize that unprecedented musical expressions can be achieved by actively incorporating these systems into artistic endeavors.

To explore this potential, we collaborated with the composer SiHyun Uhm, a former student at the Eastman School of Music and the Juilliard School of Music, to

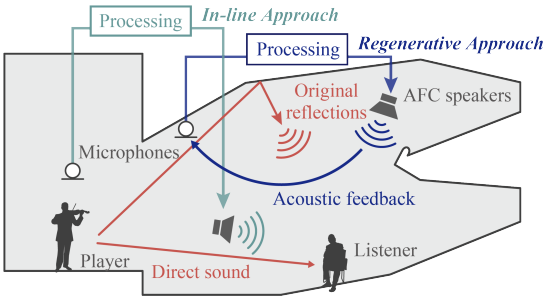


Fig. 1: Conceptual illustration of one of the AFC's two core systems: ***REV*** System

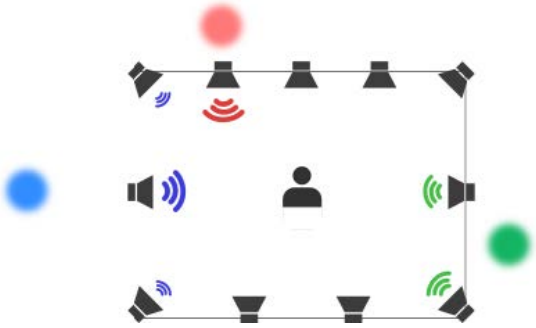


Fig. 2: Conceptual illustration of one of the AFC's two core systems: ***IMAGE*** System

1: Information of the concert and contributors

Name	AFC Workshop - Strig Quartet For AFC System -	
Date	July 29, 2022	
Venue	Yamaha Ginza Studio, Tokyo, Japan	
Composer	Uhm SiHyun	
Technical Advisor	Kim Sungyoung	
Program	String Quartet No. 2 For AFC System	
Playing time	Approx. 12 min.	
Performer	Violin	Nahoko Wakatabi
	Violin	Saori Nakazawa
	Viola	Kiyoko Nakamura
	Cello	Naoki Oiwa

create a new piece that utilizes immersive sound systems as a core component. This collaboration resulted in a new string quartet (String Quartet No. 2). We held a world premiere concert of this music on July 29, 2022, at Yamaha Ginza Studio. Subsequently, we collected feedback on the system's effects through audience surveys conducted during the event. A list of contributors for the event is in Table 1.

For this performance, we utilized Yamaha's Active Field Control (AFC) system [2, 3] as an immersive sound system, which specifically controls spatial reverberation and sound image parameters. This paper serves as a report that summarizes how we planned and conducted the concert and shares experiential knowledge from the concert for appropriate usage of these immersive sound systems in future similar applications.

2 Immersive Sound System: AFC

Two factors represent the spatial information of a sound field: the sound environment and sound elements [4]. The AFC system is an innovative sound system designed to enhance users' auditory immersion by manipulating these two components. The system comprises two core sub-systems: the Reverberation Control System (***REV***) and the Sound Image Control System (***IMAGE***).

The ***REV*** system primarily influences the "sound environment" by optimizing the length of reverberation and the spatial impression of the target sound field. In contrast, the ***IMAGE*** system manages "sound elements" by adjusting the direction and size of sound, which are crucial aspects of sound element information.

The AFC system was originally developed as an acoustic design tool for controlling the sound field in a room. In 2021, Yamaha expanded its functionality by implementing the sound image control function in addition to the conventional reverberation control function. This enhancement allows for complete control of reproduced sound fields, encompassing both sound image manipulation and reverberation control.

2.1 *REV* System

The ***REV*** system naturally alters the primary auditory characteristics of room acoustics, such as reverberation, early reflections, and loudness, by employing electroacoustic peripherals in conjunction with advanced signal processing techniques. Generally, acoustic control systems can be categorized into two types: in-line and regenerative methods [5]. The in-line system employs



Fig. 3: Score Example



Fig. 4: RIT Studio

a processor that adds reverberation to the signal captured by a microphone array placed close to the sound source and then plays it back through the loudspeakers. In contrast, the regenerative system actively uses an acoustic feedback loop in which diffuse sound is captured by a distant microphone array, separate from the sound source, and then reproduced through a loudspeaker. Since the reproduced signal becomes an additional input signal to the microphone array, we refer to this as a "regenerative" system.

In the current AFC ***REV*** system, both the in-line and regenerative approaches are implemented. By combining them, users can manipulate natural and pleasing reverberation that best suits the content. The basic model of the ***REV*** system is illustrated in Figure 1. The ***REV*** system can adapt impulse response (IR) data recorded in an actual hall. Specifically, the in-line method utilizes IR data recorded at the boundaries of the hall walls. These lateral reflections play a crucial role in obtaining the required spatial impressions associated with room-size-related acoustic parameters.

2.2 *IMAGE* System

The ***IMAGE*** system controls the direction and location of sound elements using three-dimensional (3D) amplitude panning, based on a psychoacoustical model [6]. A conceptual diagram of the ***IMAGE*** system is presented in Figure 2. The system supports object-based audio (OBA) [7] and is compatible with various speaker placements and configurations. Generally, the representation of location data in OBA such as digital audio workstation (DAW) is normalized, thus the ***IMAGE*** system has the function to automatically expand the normalized data into the real sound field space.

The ***IMAGE*** system employs open sound control (OSC) [8] to receive information, such as the position and size of the sound image. This allows for the control of sound image information from a DAW, mixing console, or PC software capable of manipulating OSC signals.

3 Music Production

3.1 Overview

Immersive sound systems are already being utilized in various content production fields, such as films, pop concerts, and installation art. Currently, many of these applications focus on controlling sound elements. However, considering immersive sound systems as tools that can manage the entire soundscape, encompassing both sound elements and the sound environment, presents a challenging yet valuable approach.

While there have been experimental reports of actively using sound environment control in multiple events with diverse content [9, 10], it has not yet become widespread, leaving a multitude of unexplored expressive possibilities. Therefore, we believe that combining the control of sound elements and the sound environment, and actively managing the entire auditory scene, will open up more possibilities for content creators and enhance their potential for unprecedented and unexplored artistic creativity.

In this study, to explore the system's potential for these new artistic expressions in music composition, we attempted to create a classical string quartet piece that actively incorporates changes in reverberation and sound image positions. We asked the composer to devise a new notational method that indicates the changes in reverberation and sound positions within traditional sheet music. As a result, alongside musical notes, the detailed parameters of the system were denoted alongside conventional musical notation, as shown in Figure 3.

3.2 Production Process

In this composition, the composer chose "expression of changes in time and space" as the central theme. To facilitate the composer's creative process, we established an AFC system in a studio at the Rochester Institute of Technology (RIT) to serve as her workspace. This allowed her to experiment with the system's functions and intended effects. You can see an image of the studio in Figure 4. During these experimental sessions with the system, we sought to align the musical composition with auditory spatial imagery to explore effective methods of using the system for artistic expression.

Our ultimate goals for the composition were twofold:

1. To create total sonic impressions that harmonized with the scenes depicted in the composed music.
2. To reproduce sound effects that could move freely within the space.

To achieve the first goal, we used the ***REV*** system to control auditory spatial impressions, enhancing immersion in the scenes portrayed in the composition. We prepared four presets of resonances that evoke the scenes in the composition, with instructions for switching between presets provided in the score. Detailed auditory impressions for each preset are outlined in Table 2, and switching instructions appear 43 times throughout the composition.

For the second goal, we employed the ***IMAGE*** system to spatially reproduce the sound effects in three dimensions. The composer created the sound effects and specified the timing for playback in the score. Information regarding the position, size, and movement of the sound effect images was stored as object audio data in the DAW and synchronized with the live performance. To ensure synchronization, the sound engineer operated the playback and stop functions while referencing the score during the performance.

4 Conducting Experimental Concert

To assess the effectiveness of the system, we invited approximately 100 individuals from the audio industry to participate in an experimental concert (Table 1). The concert consisted of three parts:

1. A demonstration of the AFC system.
2. A performance by a string quartet, with the AFC system integrated.
3. An interview session with the composer, SiHyun Uhm, and technical advisor, Dr. Sungyoung Kim.

You can see a snapshot of the string quartet performance in Figure 6, capturing a moment from this event.

Following the entire program, we distributed questionnaires to the attendees, soliciting their opinions on innovative applications of the immersive sound system.

4.1 Creation of Experimental Concert Environment

The system configuration and venue photographs are presented in Figures 7, 8, and 9. The system utilized 16 input microphones and 53 reproduction loudspeakers.

As mentioned earlier, the ***REV*** system combined the In-line and Regenerative methods, aiming to achieve resonance suitable for the piece. Four microphones were closely positioned to each instrument of the string quartet, serving as dedicated inputs for the In-line method. The remaining twelve microphones were directional and omni-directional, positioned above the stage and audience seats, respectively.

Once the system was installed, the reverberation settings were adjusted to match the composer's desired sound space.

1. In Setting 0, the ***REV*** system was turned off to evoke a desert-like scene, featuring a clear sound field with short reverberations based on the venue's inherent acoustics.

2: Scene expression by ***REV*** system and acoustic index values in concert environment

Preset	Composer's impression	RT [s]	C80 [dB]
Setting 0	Dry desert scene	0.6	9.0
Setting 1	Wind blowing scene	1.8	0.7
Setting 2	Plateau scene	1.9	2.9
Setting 3	Mountain tops and deep scenes	5.7	3.2

* The composer's impression is the scene originally envisioned in the early stages of the composition.
* Reverberation time is 250-2kHz, C80 is 500-2kHz Oct. band average

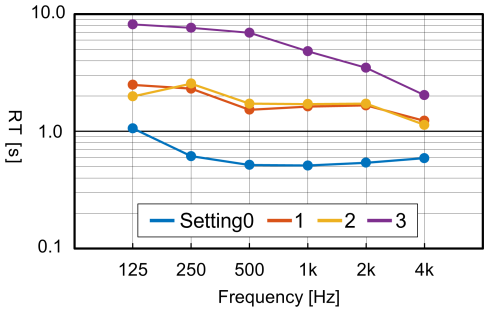


Fig. 5: Frequency characteristics of reverberation time



Fig. 6: Experimental concert

2. Setting 1 aimed to recreate an imaginary scene of a windy forest with a relatively short reverberation time. The impression of the windy forest emerged from the interplay between musical components of the piece and the acoustic atmosphere with shorter reverberation.

3. In Setting 2, the reverberation length was set the same as in Setting 1, but the energy of early reflections was increased to create a clear sound field, expressing a plateau scene.

4. Setting 3 called for an extremely long reverberant sound field to portray a fantastical mountain scene.

The measured reverberation time and the intelligibility index C80[11] for each preset are provided in Table 2.

4.2 Comments from the audience

Below are selected comments from the visitors' after-the-concert survey results:

- I found great enjoyment in the piece due to its distinctive approach to composition and its real-time spatial conception within the classical genre.
- Various sound components, including direct sound, early reflections, and reverberations, were meticulously controlled, resulting in a noticeable alteration in the perception of space.
- The spatial resonance underwent gradual changes, occurring every few bars or dozens of bars. However, I was occasionally distracted by these alterations in resonance, which somewhat diminished my appreciation for the other musical elements.
- I thought that a contemporary composer could envision multiple distinctive acoustic environments, such as a beach, underground space, or forest, and effectively incorporate them into an opera or theater production.

Some attendees provided positive feedback, noting that the alterations in sound space during the performance significantly enhanced the "musical expressivity." These comments affirmed that the composer's intention successfully resonated with the audience.

However, there were also individuals who expressed discomfort with the frequent shifts in the acoustic conditions of the performance space. This discomfort may stem from the limitation that, in the current setup, it is only possible to change the acoustics instantaneously

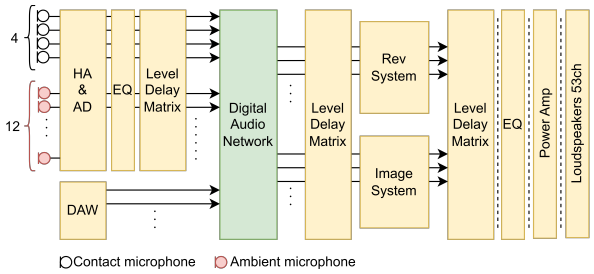


Fig. 7: System configuration of concert

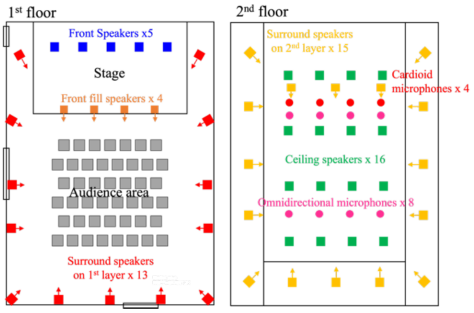


Fig. 8: Equipment configuration of concert



Fig. 9: Experimental concert venue

by switching between presets, rather than providing continuous adjustments.

4.3 Comments from the composer

After the concert, the composer was interviewed about her opinion on the system, summary of which is below:

> I created a work that moves back and forth between a fast section and a slow section, with the fast section evoking the image of a "desert" and the slow section evoking the image of a "mountain." The two different scenes have different characteristics, and the final goal was to merge the two scenes by uniting the spaces.
>
> Without the system, the music was an abstract description of a scene, but with the system, I was able to imagine the details of the scene, the specific place, and even the time of day. The space created by the system allowed us to create the atmosphere of the place and to deeply immerse ourselves in the sound.

As intended during the production, the utilization of an immersive sound system to manipulate spatial characteristics is believed to have expanded the creators' expressive possibilities.

5 Conclusion

A new musical composition was created, incorporating a state-of-the-art immersive sound system to enhance the creativity and expressiveness of content creators. By adeptly controlling two spatial components—sound environment and sound elements—the composer successfully conveyed her intentions to the audience. While this endeavor to integrate our space-control technology was initially limited to classical music, we envision its potential to expand creative possibilities in other musical genres and the arts. Looking ahead, our goal is to develop a more versatile system with greater flexibility to manipulate acoustic space in alignment with the creative requirements and ideas of content creators.

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