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3aAAa2. Active field control using sound field generation techniques Case study of a live concert at a virtual Renaissance church

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In the Renaissance era, musical culture was centered around and spread through churches. To appreciate Renaissance music, it is important to account for the influence of the acoustics of churches in that era so that audiences today can experience music in the same way that people did in the Renaissance. We used an Active Field Control system to reproduce the acoustics of a Renaissance church using the measured impulse responses (IRs) of a church. The system picked up the direct response of the performance, convolved it with the measured IRs, and reproduced the resulting sound using loudspeakers located around the room. The loudspeaker positions in the reproduction sound field were equivalent to the positions where the IRs had been measured at the church. This technique allowed us to convincingly recreate, in the reproduction sound field, not only the reverberation time but also the spatial impressions of the church. In addition, we modified the IRs so that the inherent acoustical characteristics of the performance space would have less influence on the re-creation of the target church acoustics. We used a 6-channel recording/reproduction system to evaluate the modification of the IRs and the impressions of the recreated acoustics in the room.

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INTRODUCTION

When a person is enjoying music at a concert, the acoustical conditions of the venue have a significant impact on his or her subjective impression and evaluation of the music. It has also been reported that a musician's performance is affected by the acoustical conditions.[1]

The characteristics of a music performance spaces change as time passes. Fundamentally, live musical performance and appreciation happen at the same time and the same place. There is no constraint that a specific type of music has to take place under specific acoustical conditions. Moreover, performance spaces are selected not only for their acoustical conditions, but also for other factors, such as the capacity and convenience of the venue. Nonetheless, some spaces maintain unique acoustical fingerprints over generations. For example, the Basilica di San Marco in Venice was one of the central locations for Renaissance music in Italy. And there are prominent auditoria existing even today that were the primary locations for musical performance and appreciation in the latter half of the 19th century, when Romantic music was making great strides. Therefore, to appreciate the music composed in a certain acoustical condition, the acoustics of a venue should be also delivered to audiences. And if there was a system providing the acoustics of a venue where the music was composed, it would help both musicians and audiences better appreciate the musical performance.

To achieve this feature with a reasonable cost, we have developed an Active Field Control (AFC) system that controls the acoustical conditions of a space. To date, we have used this system for various projects. After numerous professional installations and operations of the system around the world, we faced a question: what kind of spatial impression should be recreated for music composed during the Renaissance era? To experimentally answer this question, we organized a concert where the acoustics of a Renaissance church were recreated and the music of the period was performed in the prevalent acoustical conditions of the time. This concert provided musicians and audiences with a chance to appreciate music within the acoustics of a Renaissance church. For this project, we utilized an AFC system that incorporated actual impulse response (IR) measurements and reproduced not only the reverberation time but also the spatial impressions of a Renaissance church. This paper reports on recreation of coherent spatial impressions of a Renaissance church, design of the system, implementation in a modern multi-purpose hall, and subsequent subjective evaluation results.

PHOTO 1. A live concert at a virtual Renaissance church

ACTIVE FIELD CONTROL USING SOUND FIELD GENERATION TECHNIQUE

Figures 1 and 2 show how the AFC system for the concert was configured. The sound from the stage was picked up by four directional microphones that were installed above the stage. After the signals underwent FIR filter convolution in the signal processing unit, they were reproduced through multiple loudspeakers. The FIR convolution coefficients were determined using IRs of a target sound field, and these coefficients were used to reproduce the desired sound field characteristics. Our goal was to achieve the acoustical conditions of a church within a reproduction venue. After examining our IR database and taking into consideration the similarities of spatial configurations and interior materials to a Renaissance church, we decided to use the data that we acquired from a church located at the campus of a university in England. We measured at multiple positions in the church. To recreate the acoustical characteristics of the church, including the spatial impression, we chose to use the data that was measured at each of the points corresponding to the locations of the speakers installed in the perimeter within the reproduction sound field.

The directional microphones were located along the walls and directed toward the surfaces. This configuration was used to retain the spatial reverberation characteristics by capturing reflections from the walls. The configuration also had the acoustical advantage of maintaining common characteristics through measurement in the same space while also enabling the measurement of IRs with characteristics that were as different as possible (low coherence).

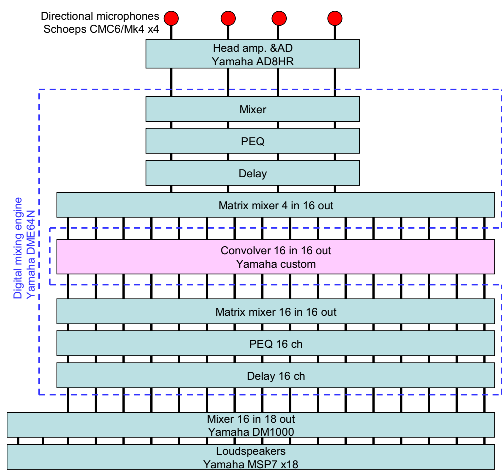

FIGURE 1. Block diagram of the AFC system

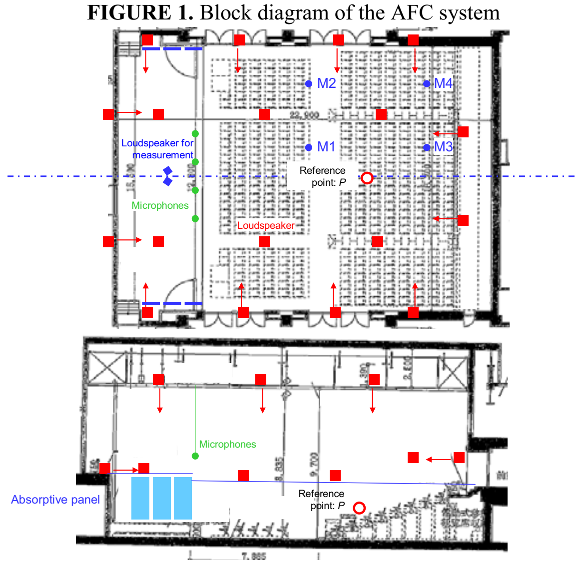

FIGURE 2. Equipment placement and points of measurement for the reproduction field

CONCEPT OF SOUND FIELD GENERATION TECHNIQUE

In the concert, we attempted to also reproduce the spatial impression of the target space. Below, we will examine the design guidelines for the system that was used for the concert. Figure 3 illustrates these guidelines. The transfer function $h_{\Omega o}$ from the sound source S to the reference point P within the target sound field Ωo is represented by equation (1).

$$h_{\Omega_o} = d_{S-P} + r_{\Omega_o S-P} \tag{1}$$

d_{S-P} : direct sound from the sound source S
$r_{\Omega oS-P}$: reflections at the target field Ω_o

Meanwhile, the transfer function h_{Ω} from the sound source S to the reference point P within the reproduction sound field Ω when the AFC system is used is represented by equation (2).

$$h_{\Omega} = d_{S-P} + \underline{r_{\Omega S-P} + \sum d_{Si-P} + \sum r_{\Omega Si-P}} \tag{2}$$

d_{S-P} : direct sound from the sound source S
$r_{\Omega S-P}$: reflections at the reproduction field Ω
Σd_{Si-P} : direct sound from the system speaker S_i
$\Sigma r_{\Omega Si-P}$: reflections reproduced by the system speaker S_i at the reproduction field Ω

Here, Σd_{Si-P}, and $\Sigma r_{\Omega Si-P}$ are represented by the following equations, respectively.

$$\sum d_{Si-P} = \sum\left(d_{S-M} * FIR_i * d_{Si-P}\right) + \sum\left(r_{\Omega S-M} * FIR_i * d_{Si-P}\right) \cong r_{\Omega_o S-P} \tag{3}$$

$$\sum r_{\Omega Si-P} = \sum\left(d_{S-M} * FIR_i * r_{\Omega Si-P}\right) + \sum\left(r_{\Omega S-M} * FIR_i * r_{\Omega Si-P}\right) \tag{4}$$

d_{S-M} : direct sound from the sound source S to the system microphone M
FIR_i : FIR convolution coefficient of the system
d_{Si-P} : direct sound from the system speaker S_i to the reference point P
$r_{\Omega S-M}$: reflections from the sound source S to the system microphone M
$r_{\Omega Si-P}$: reflections from the system speaker S_i to the reference point P

When the underlined portion of equation (2) approaches $r_{\Omega oS-P}$, the reproduction of the target sound field is possible. If we assume that the use of directional microphones will enable us to ignore $r_{\Omega S-M}$, Σd_{Si-P} can be regarded as $r_{\Omega oS-P}$, and it becomes necessary to remove two elements: (1) the reflected sound $r_{\Omega S-P}$ in the reproduction sound field Ω that is caused by sound source S and (2) the reflected sound $\Sigma r_{\Omega Si-P}$ in the reproduction sound field Ω that is caused by system speakers S_i. We removed element (1) by adding sound absorption to the stage walls, which receive a great deal of influence from direct sound, and removed element (2) by calibrating the FIR convolution coefficients. We performed the calibrations for handling element (2) by multiplying each convolution coefficient by an exponential function with temporal attenuation.[2]

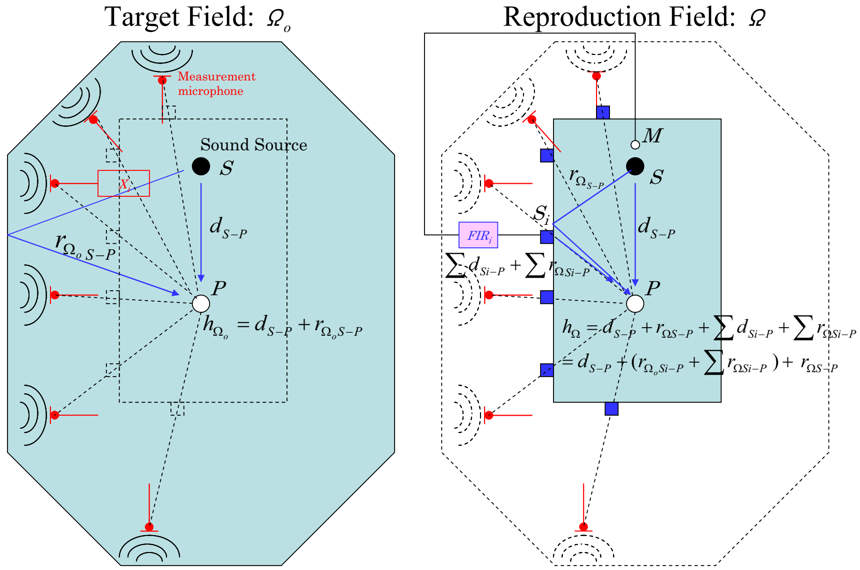

FIGURE 3. Concept of the sound field generation technique

SOUND FIELD SIMULATION USING 6-CH RECORDING/REPRODUCTION SYSTEM

To check the system capability in advance to actual implementation, we used measured acoustical responses of the reproduction sound field using the 6-ch recording/reproduction system for 3-dimensional auralization of sound fields shown in figure 4.[3] This system (hereafter referred to 6-ch system) first captures auditory impressions as well as localization of a space using a microphone that picks up sound information incoming from front, back, left, right, top, and bottom direction. Then each of captured information is reproduced via a loudspeaker located at the same direction from the listening position. We took the following steps to perform a simulation using this system.

First, we installed a loudspeaker S on the stage of the reproduction sound field and measured the transfer function (h_{S-n}) to the six-directional microphone installed at reference point P. Subsequently, h_{Si-n} indicates a transfer function from a loudspeaker S_i to the six-directional microphone. We used this data to calculate the convolution coefficients for each direction as indicated in equation (5). We convolved the coefficients into a dry source and reproduced sound from separate speakers for each direction, which enabled us to aurally confirm the effect of implementing the system in the reproduction sound field.

$$h_n = h_{S-n} + \sum_i FIR_i \times h_{S_i-n} \tag{5}$$

h_n : transfer function of the direction n
h_{S-n} : transfer function of the direction n reproduced by the sound source S
FIR_i : FIR convolution coefficient for the system speaker S_i
h_{Si-n} : transfer function of the direction n reproduced by the system speaker S_i

Next we investigated the effect of the sound absorption within the stage and the effects of the calibrations to the FIR filters. To determine a decay constant for calibration, we created six types of stimuli and used them in a subjective evaluation experiment. The six types of stimuli were (1) the original sound field of the concert venue; (2) the target sound field with the system implemented and no influence from reflections; (3) the simulated sound field with the system implemented, no sound absorption, and no FIR filter compensation; (4) the simulated sound field with the system implemented, sound absorption, and no FIR filter compensation; (5) the simulated sound field with the system implemented, sound absorption, and FIR filter compensation; and (6) the simulated sound field with the system implemented, no sound absorption, and no FIR filter compensation but also with the effects of reflections from S_i completely removed (for comparison). As a result, we were able to confirm the effect of the AFC system when we compared stimuli (1) to the others. However, comparing stimuli (3) to stimuli (2), the subjective impression of stimuli (3) was too muddy and enveloped. While comparing stimuli (4) and (6) with stimuli (3), we assumed that the muddy impression mainly comes from the effect of early reflections and the enveloped impression mainly comes from the reflections added to the reproduced sound from S_i. The result of the subjective evaluation with several subjects shows that the removal of the reflections from the source on the stage and the FIR filter calibration brought the sound field closer to the target sound field. Thus we have concluded that the absorption on the stage and the technique of using FIR filter calibration with attenuation are effective. We also adjusted the decay constant while comparing stimuli (5) to stimuli (2).

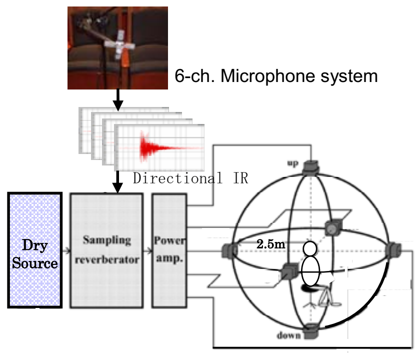

FIGURE 4. Outline of the 6-channel recording/reproduction system

SUBJECTIVE EXPERIMENT

Method of Psycho-Acoustical Experiment

After the concert, to determine whether we achieved the desired effect with the actual system, we compared the simulation data with the measured data at the reproduction sound field with the system using the 6-ch system. The evaluation was performed using the five sound fields indicated in table 1.

TABLE 1. Sound fields for subjective experiment

Case	Condition	System	Convolved FIR	Note
1	Measured	Off	-	Original sound field of the concert venue
2	Synthesized	On	Original	
3	Synthesized	On	Modified	Reflections in $h_{S\text{-}n}$ are eliminated to simulate the effect of absorption on stage
4	Measured	On	Original	Non-modified FIR filters are applied to the system just for comparison
5	Measured	On	Modified	The sound field used in the concert

The method that we used in the experiment was the MUSHRA (MUlti Stimulus test with Hidden Reference and Anchor)[4] subjective test method. The subjects were nine male acoustic engineers and one female acoustic engineer ranging from 20 to 50 years of age. We convolved the measured and simulated (synthesized) responses (listed in table 1) with two dry sound sources (flute solo: Londonderry Air and bassoon solo: Peter and the wolf). To determine how the system affects the spatial impression during a musical performance, we asked the subjects to evaluate three perceptual attributes: ASW, LEV,[5] and Clarity. We selected these attributes after careful listening and discussion on the salient percepts discriminating the sound fields.

Results and Discussion

Figure 5, 6, and 7 show the mean and 95% confidence interval of the statistical distribution of the assessment grades. Examining the evaluation indicators, we can see that the average values for the simulation and measurement follow the same trend and that FIR filter calibration achieved the desired effect. However, we can see a difference in the absolute values of the simulation and the actual measurement. This disparity might be associated with the energy balance between dry sound and generated sound field. In other words, it turned out that the level of sound field for simulation was relatively larger than the actual measurement. And this larger sound field generated wider, more enveloped, and muddier auditory impression. We believe that more faithful results can be obtained by predicting the effect of system feedback beforehand and computing and applying a gain value that can be set.

For reference, figure 8 shows the reverberation time that was measured in the reproduction sound field when the system was implemented. The measurement points were the four points indicated in figure 2 (M1―M4). Figure 8 shows that the reverberation time matches the reverberation time for the target sound field characteristics almost completely.

The subsequent audience surveys showed that they noticed significant changes of room acoustics which were more appropriate to the context of performed music. However, the some players reported that they found it difficult to perform because they were get used to the 5-second reverberation time of the church sound field, and they were confused by the difference between the spatial impression and the length of reverberation during the performance. These results show the importance of gaining experience performing in a variety of sound fields but also call attention to the issue of balancing early reflections and late sound. Also, this evaluation only addressed the appropriateness of the applied method, but in the future, the reproduction of the sound field itself should be evaluated through direct comparison with the target sound field.

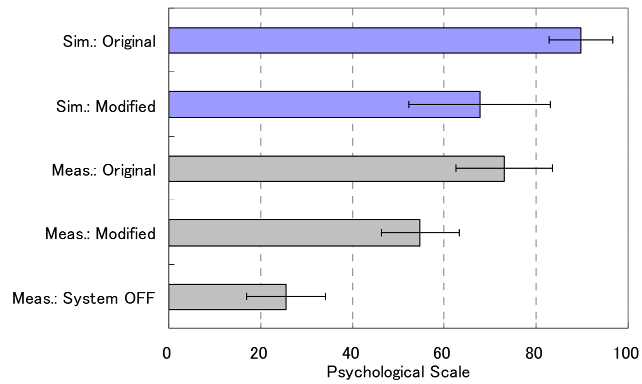

FIGURE 5. Listening test result for ASW for each condition

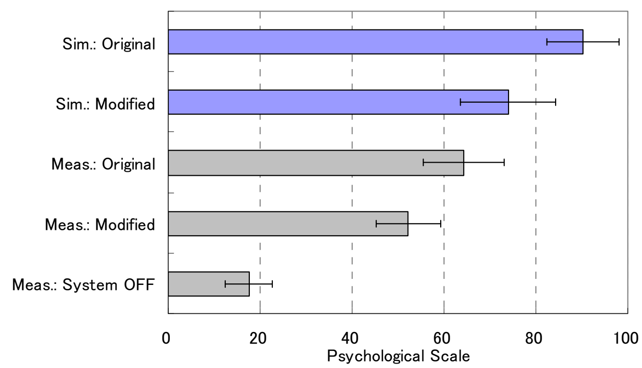

FIGURE 6. Listening test result for LEV for each condition

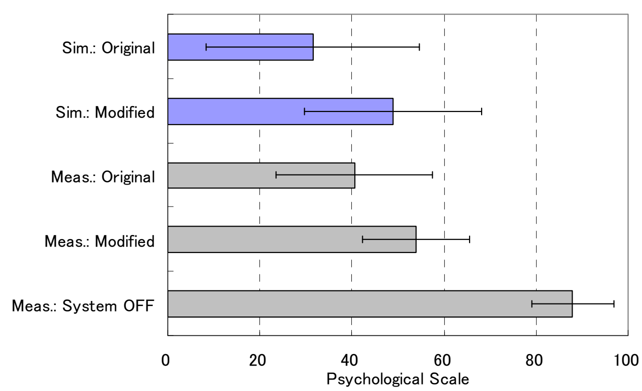

FIGURE 7. Listening test result for Clarity for each condition

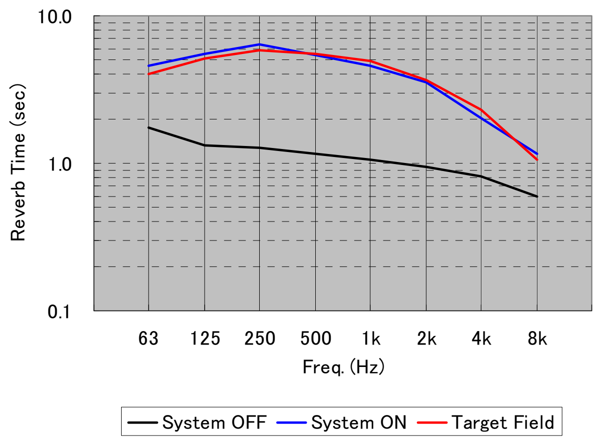

FIGURE 8. Reverberation time frequency characteristics

CONCLUSION

An AFC system was used to reproduce the acoustics of a church in a modern concert hall. By using actual IR measurements, we expected to be able to reproduce the spatial impression of the acoustics of the church. In order to minimize the influences of the reflections of the concert hall and to implement successful recreation of the church acoustics, we installed sound absorbing material in the stage and subsequently calibrated the FIR coefficients. To evaluate the effect of the system and of the FIR filter calibration, we used a 6-ch. system to simulate the reproduced sound field in advance to actual system implementation. The comparison between simulation and actual measurement with the system showed that the calibrated system generated sound field perceptually similar to the target acoustics of the church.

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