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Recording of anechoic symphony music

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When designing the acoustics of a concert hall, it would be beneficial to be able to use real recording of a symphony orchestra in auralization. The technical constraints for such recordings are high. First, the instruments have to be recorded separately, as in simultaneous recording the cross talk between microphones can not be avoided. Second, the recording room should be anechoic. Third, the instruments have different sound radiation patterns, thus the instruments should be recorded with multiple microphones around them. Therefore, we end up recording each instrument individually in an anechoic chamber with multiple microphones. To produce timing and interpretation information to players a conductor video was shown on a small display. The video included also a piano track that the players could listen to with headphones while playing his/her own part. Four short passages, from 2 to 4 minutes from different music styles were recorded. The recordings were made with 20 low-self-noise microphones, mounted on the shape of the dodecahedron. Finally, we discuss the musical and technical quality of recorded sound, and the response by the musicians, who were professional orchestra musicians.

1 Introduction

Auralization process needs an anechoic excitation signal emitted by a sound source which has a certain directivity. For auralization of concert halls the proper sound source is a full symphony orchestra in which each instrument has an own position on the stage. Unfortunately, only one compact disc of anechoic orchestral music has been published [1]. These recordings are quite noisy and the whole orchestra is recorded at the same time with close-up microphones. With this technique the signals of different instruments are not sufficiently separated due to the crosstalk between recorded signals. Recently, Vigeant et al. [2] (also mentioned in [3]) have applied the recordings of the orchestra in multi-channel auralization, but the recording process of anechoic stimulus material has not been reported. In this paper the recordings of anechoic symphonic music for auralization purposes are presented.

2 Recording Procedure

The instruments were recorded one by one in an anechoic chamber. The most significant challenge was to somehow provide information on synchronization for musicians so that they could play as an ensemble with common timing. After discussions with a few conductors the following technique was applied. The musicians played their parts by watching a conductor in a monitor and by listening to a pianist playing the whole score, see Fig. 1. This way the musicians were able to adapt their playing style and tempo, and the synchronization between different players was possible.

When playing in the anechoic chamber, musicians wore open headphones (Sennheiser HD-590) for listening to the piano track of the conductor video as well as for communication. Instead of closed headphones, open ones were used in order to help the players hear their playing without additional monitoring. In case a player would have needed to hear more of his/her own playing, one selectable microphone channel was routed optionally to the headphones. As a result, nearly all players preferred to wear headphones only over one ear. Self-monitoring option was needed only once. Despite the open design of the headphones, the openness did not cause any noticeable leakage to the microphones.

2.1 Music

The size of a typical orchestra and the complexity of the music texture varies between periods, thus different music styles were recorded. In auralization studies it is beneficial to have music for both small and large orchestras as well as music with slow and fast tempo. In the following the recorded music excerpts are described briefly.

A soprano aria of *Donna Elvira* from the opera *Don Giovanni* by *W. A. Mozart* (1756-1791) was selected to represent music of the Classical period. The music is typical classical music with a soloist and quite light and straightforward accompaniment. In addition, this aria was the only recorded passage which includes a soloist. On the other hand, the size of the orchestra characteristic to the compositions of this era is the smallest of the recorded works. Besides the string instruments, parts are written for a flute, a clarinet, a bassoon and two French horns. The number of first and second violins in orchestra is typically around 10 players each. This is the only piece recorded in whole, it has a duration of 3 min 47 sec, thus being the longest of all four passages.

L. van Beethoven's (1770-1827) Symphony no. 7 was chosen due to the strong opening chords in which the whole reverberation tail can be heard. In addition, the recorded introductory part has string *crescendos* with which concert hall acoustics can be easily judged. Therefore, it is regarded to be a very suitable piece to study the acoustics of a concert hall. For the musical style, it also represents the late Classical period. The score includes parts for two flutes, oboes, clarinets, bassoons, French horns and trumpets in addition to the strings and timpani. The size of the string sections is slightly larger than in Mozart's music, as 12 first and second violins is a typical number. Bars 1-53 from I movement were recorded and the duration is 3 min 11 sec.

A. Bruckner's (1824-1896) Symphony no. 8 in turn represents the late Romantic period, and the overall dynamics of the music as well as the size of the orchestra are larger than at Classical period. The score is written for a full symphony orchestra, containing parts for trombones as well as a tuba. Long passages for strings are written in *tremolo* which is typical to all Bruckner's symphonies. While the texture is still quite conventional, it is noticeably dense, and many sections are played in *tutti* and *fortissimo*. The recorded section contains bars 1-61 from the II movement, thus being the shortest passage with duration of 1 min 27 sec.

G. Mahler's (1860-1911) Symphony no. 1 was se-

Figure 1: The recording configuration in an anechoic chamber. A musician followed the conductor video through the monitor and listened to the piano version of the whole score while playing his/her own part.

lected as another late Romantic composition. As the music is composed in the same period as Bruckner's symphony, they are both great examples of works which require large orchestras. However, the musical texture of Bruckner's music is quite conventional while Mahler is considerably more complex music. Bars 1-85 from the IV movement were recorded. The recorded excerpt has a duration of 2 min 12 sec.

2.2 Conductor video

A video of the conductor was recorded with a digital video camera with external microphones. Only the conductor was included in the picture as can be seen in Fig. 1.

The conductor on the video was a professional conductor. The pianist who played on the conductor video was a professional *répétiteur* but also a conductor as well. The piano track was played directly from the conductor's scores. Despite the complexity of the full score, particularly in Mahler's symphony, the pianist managed to play all essential details with only a little variation in tempo.

Mozart's aria was recorded with a soprano soloist in order to provide more predictable reference for the musicians playing along the video in recording situation. Finally, the four selected passages were edited to separate Quicktime movies.

3 Design and recording equipment

The anechoic chamber used for the recordings is a cube shaped, and the free measure between wedge tips is at minimum 4.2 m. With an absorption wedge length of 80 cm, the room is assumed to be anechoic at frequencies above 100 Hz.

3.1 Microphones

For recording sound in multiple directions, 22 Røde NT1-A -type large-diaphragm microphones were installed to the anechoic chamber. According to the manufacturer data, NT1-A microphones feature very low self-noise ($L_{noise,A} = 5$ dB).

Table 1: Elevation and azimuth angles, distances and used numbering of microphones. Distances from the center of the room is denoted with r.

Mic.	Ele	Azi	r	Mic.	Ele	Azi	r
1	52.6	0	2.43	**11**	-10.8	36	2.16
2	52.6	72	2.24	**12**	-10.8	108	2.03
3	52.6	144	2.46	**13**	-10.8	180	1.87
4	52.6	216	2.49	**14**	-10.8	252	1.80
5	52.6	288	2.49	**15**	-10.8	324	2.06
6	10.8	0	2.30	**16**	-52.6	36	2.05
7	10.8	72	1.94	**17**	-52.6	108	2.04
8	10.8	144	1.92	**18**	-52.6	180	2.00
9	10.8	216	2.14	**19**	-52.6	252	1.92
10	10.8	288	2.25	**20**	-52.6	324	2.08
				21	0	0	2.21
				22	90	0	2.06

Twenty microphones were geometrically positioned to form a shape of the dodecahedron. This shape was selected due to the equal distances between adjacent vertices and the rough representation of a spherical surface. The dodecahedron was oriented to form four horizontal microphone levels, each consisting of five microphones in a regular pentagon. Besides the microphones in the dodecahedron, two additional microphones of the same kind were positioned to the front and above directions from the center point. The numbering, angles and distances of microphones are presented in Table 1.

The defined center position was selected as the position of the head of the musician during recordings. Another possibility would have been the acoustical center position of each instrument. However, the acoustical center for each instrument would be difficult or even impossible to define. Exceptions from the head position were made in three cases, where the instrument is commonly played other than sitting: contrabass, percussions and singing.

The detailed description of other recording equipment, system equalization, as well as analysis of directivities of instruments are left out from this article, and they will be discussed in forthcoming articles.

4 Recordings

4.1 Musicians

Professional musicians were collected from Finnish National Opera, Radio Symphony Orchestra, Helsinki Philharmonic Orchestra, and Tapiola Sinfonietta. Only one musician per instrument played all parts one after another.

As large orchestras have up to 16 players per a violin part, a single violinist alone cannot produce similar breadth in the sound as several musicians playing in *unisono*. However, based on our previous studies [4] it should be enough for auralization purposes to record only one of each string instrument. Furthermore, several takes for each part were expected to be recorded. There-

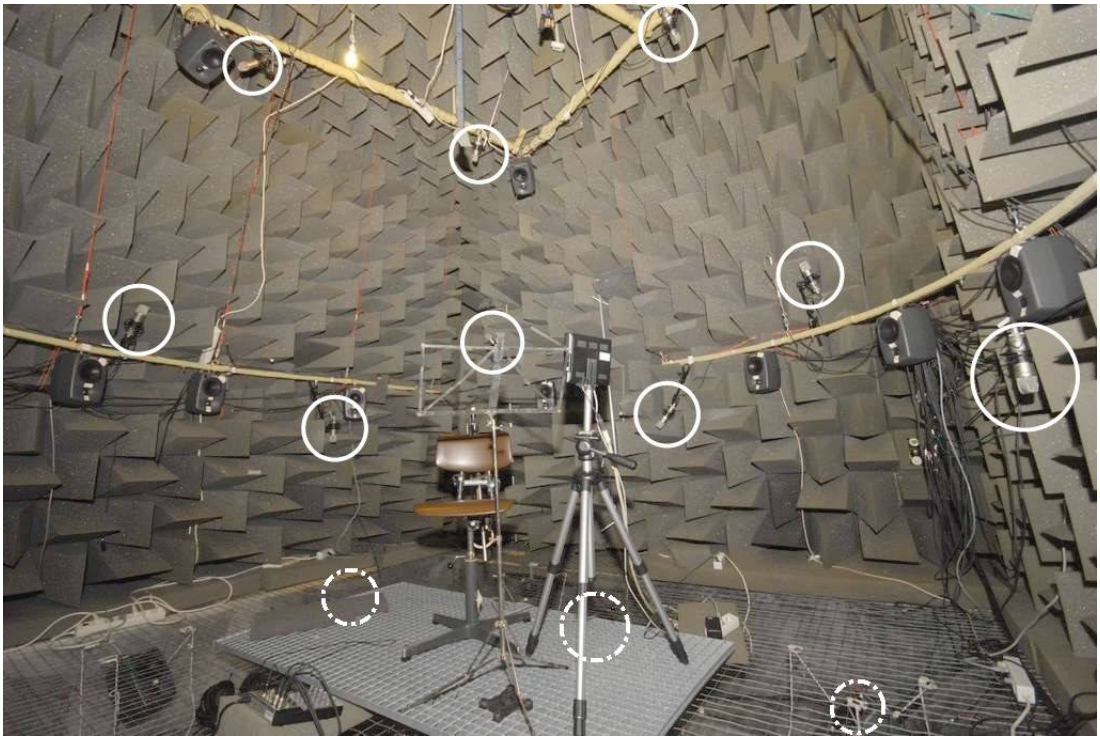

Figure 2: Some microphone positions in the anechoic recording system.

fore multiple different takes with only a little faults could be used after all to produce the impression of several musicians.

One problem was predicted relating to the anechoic recording environment. Because the room did not provide any acoustic support, especially the string players were expected to push their playing in order to produce a larger sound. Due to the absence of any reverberation, pushing is easily audible as bad sound quality. Therefore, each musician was specifically instructed not to use any excess force but instead to play as naturally as possible.

Every musician was first introduced to the anechoic room and the recording system when arriving to the recording session and instructions on the correct positioning and playing style were given. Each instrument was tuned with an "a" note recorded from the same piano as in the conductor video (a = 442 Hz), although some musicians also used a tuning meter.

Actual recordings were usually commenced with Mozart or Beethoven, as these passages were the most conventional and gave a good opportunity to get familiar with the recording procedure. As expected, these excerpts were completed with least takes or challenges. On the other hand, they both contain very delicate sections requiring accurate and consistent timing.

Mahler's and Bruckner's symphonies required recording parts in shorter sections. Most of the brass instrument parts in Mahler's symphony were recorded in multiple segments, since many of the parts included sections where it seemed to be particularly easy to accidentally hit a wrong tone.

Recording some instruments in Bruckner's symphony was approached rather differently than written in the score. With violin parts, keeping in tune in long, high notes proved out to be very difficult but also exhausting while playing *tremolo* in *fortissimo*. Therefore an alternate method was applied. First acceptable takes of all *divisi* in the whole passage were played in steady sixteenth notes with correct dynamics. Thus, it was possible to play the excerpt entirely without fatigue and still keeping in tune. After that second versions were recorded in *tremolo* but this time softly in *mezzo-piano*, mostly disregarding the dynamic indications. Thus, we obtained separate takes for different playing techniques that were utilized in the post-processing later on. As viola parts were recorded shortly after violins, the method described above was utilized from the beginning with success.

Each player were given opportunities to listen to their recorded parts once in a while during recording breaks. For instance, the best takes from all French horn parts were combined so that any need for doing another take would have been immediately recognized.

After all other instruments, the soprano soloist was recorded. Because the original conductor video of Mozart's aria included the soprano, a second version of the video was constructed before the actual recording. Here the audio track was changed to the ensemble of instrument recordings that were already completed at that time.

In the end, a total of 14 professional musicians were recorded, each session lasting from 1.5 to 6 hours.

4.2 Comments from musicians

All musicians were enthusiastic about this project and they were curious to hear the final results. Some of the players were also interested in the directivity of their own instrument.

Some musicians were slightly wary of the recording environment, as this was their first visit to an anechoic

chamber. Despite the unnatural environment, all musicians easily adapted to the situation and were able to play with good intonation and high quality.

Some comments were received concerning the style of the conductor. Since the musicians were from different orchestras, each player interpreted the conducting beat on the video by the tradition of his/her orchestra. However, the piano track helped to quickly find the correct interpretation.

5 Post-processing

To gather takes from all recorded instruments and to form an ensemble playing together, editing was required. After recording all the planned material, the prospective takes for each part were selected by listening carefully all the accepted takes for finding missed notes or off-tempo passages.

In the first editing stage, one complete take was joined from several clips, if necessary. A common task was to replace accidental wrong notes on wind instruments in otherwise good take. All editing was performed in sample-accurate manner, thus the length of resulting files were kept unchanged. At this stage any further editing was not performed.

Second editing stage comprised importing a whole instrument part to REAPER audio editing software [5]. This software allowed the simultaneous editing of all 22 microphone tracks as this feature is very important for maintaining synchronization in all channels. This editing stage was essential for correcting any timing inaccuracy between the instruments. As a sophisticated feature in the multi-track software, crossfades were automatically created for all edit points, which provided satisfying results rather easily.

The editing process in the latter software was performed as follows. First imported parts in each passage were edited by using the piano track as a timing reference. These parts included usually some string instrument parts and a wind instrument. Timing inaccuracies were corrected, and finished stacks of 22 microphone tracks were rendered into individual files. After the first completed parts, the piano track was muted and the actual instrument recordings were used as timing reference from this point forward. One microphone channel for each of the completed parts were then left to represent the part in question for the editing of next imported parts. This cycle of importing, editing and rendering was repeated until all parts were completed.

The goal in editing was not to create an unnaturally accurate synchronization. Therefore slight timing discrepancies were left unchanged. However, all the corrections were attempted to accomplish in a delicate manner so that the edits would not be easily perceived even by listening individual tracks. The number of performed edits was approximately 2-3 on average in each accepted take.

Of the four recorded music examples, Mozart's aria was considered to require least editing as it had the smallest number of instruments. However, as the soloist was in the lead with the conductor, the pianist had to adapt to the tempo more than in other pieces. This caused some irregularities in the rhythm and ultimately led to some passages being slightly out of tempo. The aria also featured a *fermata* pause in the middle. Synchronizing the tempo right after this pause required minor adjustments in all parts. Thus, it is noticeable that musical works allowing a soloist more freedom are very sensitive to the reference track.

On the other hand, Beethoven's Symphony no. 7 was regarded the most challenging from the synchronization point of view. This was noticed during editing, as more deviations concerning the rhythm had to be corrected in long sixteenth note scales and delicate segments requiring accurate articulation. Parts played by the same musician were better in time with each other than with other instrument parts. This indicates that a professional player can maintain similar interpretation through a recording session. The first chord did not require as much editing as anticipated, although minor adjustments were necessary.

Bruckner's symphony was not presenting any serious problems in editing. While it resulted in the largest number of tracks and parts, the rhythm in the texture is straightforward, thus being easier for the players to follow in tempo. Most editing work was caused by the inaccuracies between instrument groups.

The parts in Mahler's symphony with more complex rhythms were relatively well in tempo. The introductory part presented some inaccuracies in the beginnings of long notes in *unisono* after rapid quintuplets and sixteenth note passages. Towards the end of the excerpt, the piano track had sudden changes in the tempo. This was reflected to the violin part recordings and is noticeable even after editing attempts.

6 Discussion

6.1 Equipment

The recording room was not totally anechoic below 100 Hz. The instruments producing fundamental frequencies significantly below 100 Hz were timpani, tuba, contrabass, and cello. The faint reverberation at low frequencies was not considered as a problem, since these instruments have a noticeable decay time, thus reducing the importance of totally anechoic conditions. However, the low frequency reflections make the frequency response of the microphones non-flat, but these effects can be compensated.

Of all recorded instruments only the tuba succeeded in producing sound level that exceeded the maximum level in one microphone channel. During the recording of Bruckner's symphony, the signal of the microphone just above the bell was distorted. Fortunately, this was noticed immediately after the take, and a new one was recorded with slightly softer tone to prevent clipping.

6.2 Recording

Of the larger number of complete takes of violin and viola parts, more than just one usable take could be constructed. In Bruckner's symphony, a total of 20 string instrument tracks were edited. This is expected to be beneficial in the future applications by providing a richer

sound, as consecutive takes are always a little different. Even more convincing imitation for an instrument section could have been achieved by recording multiple individual instruments.

The piano track on the conductor video was regarded very helpful in maintaining synchronization and keeping in tune. The need for editing would have most certainly been enormous compared to the results with the piano track. Fortunately, any major audible problems with playing in tune were not experienced, as there would be very little to be done at the post-processing stage. Interestingly, hearing the piano while playing had a strong influence on the rhythm of actual playing. This was noticeable in some passages in which the piano was not exactly in tempo. As a result most players followed the piano instead of the conductor. However, individual timing mistakes in the piano track did not affect to the playing in tempo.

6.3 Post-processing

An interesting result was noticed while editing different parts. In some passages, all parts performed by a single musician featured a common dissimilarity compared to parts on other instruments. Therefore a few notes needing editing on one part often indicated an upcoming need for editing on other parts as well. One explanation for this could be the strong influence of following the reference piano track, as noticed with Mozart's aria.

7 Applications

The motivation for the presented recordings was twofold, to produce high quality stimulus for auralization studies and to gather directivity data of musical instruments. The analysis of the directivity of musical instruments is not presented in this article, it remains as future work.

In auralization studies the performed recordings can be applied at least in two ways. First one is to take only recordings with one single microphone for each instrument and apply these recordings in multiple point sources in a concert hall model. The directivity of the instruments can be taken into account by filtering this single signal according to the directivity of the particular instrument, as presented by Savioja et al. [6]. Another way to represent a sound source in auralization is so called multi-channel auralization, in which a point source emits different anechoic signals to different directions [7].

Another usage of the anechoic symphonic recordings would be in concert hall acoustics evaluations. The individual instrument recordings can be played from dozens of loudspeaker distributed on the stage of an existing concert hall. This "loudspeaker orchestra" can be listened in-situ in the hall, but it can also be recorded, e.g., with a dummy head. When the whole reproduction and recording system is careful calibrated, such a loudspeaker orchestra enables an A/B test of different concert halls in the laboratory environment. In other words, the calibrated loudspeaker orchestra acts as a reference sound source which is exactly the same in each hall. Although the directivities of the loudspeakers are not equal as directivities of musical instruments, this method looks very promising in future concert hall acoustics studies.

7.1 Demonstrations

Two-channel downmixes of anechoic music and example concert hall auralizations are available in the Internet. In addition, all the individual audio tracks will be freely available for academic use on request. See more information at http://auralization.tkk.fi.

8 Conclusions

An anechoic recordings of orchestra instruments have been described from multiple aspects. As a result, multichannel anechoic symphony orchestra recordings were obtained from four different musical styles ranging from Mozart to Mahler. Experiences of the recordings and post-processing were discussed from various point of views. Recorded material are planned to be used in concert hall auralization as well as in studying existing halls with repeatable excitation signals. The result of the project, four passages of symphonic music are provided to be used freely for academic research.

Acknowledgments

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References

[1] Denon. Anechoic orchestral music recording. Audio CD, Denon Records, 1995. ASIN: B0000034M9.

[2] M. Vigeant, L.M. Wang, and J.H. Rindel. Investigations of multi-channel auralization technique for solo instruments and orchestra. In *the 19th International Congress on Acoustics (ICA'2007)*, Madrid, Spain, September 2-7 2007. Paper RBA-15-004.

[3] M. Vorländer. *Auralization – Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality*. Springer-Verlag, 2008.

[4] T. Lokki. How many point sources is needed to represent strings in auralization? In *the International Symposium on Room Acoustics (ISRA'2007)*, Seville, Spain, September 10-12 2007. Paper P11.

[5] http://www.cockos.com/reaper/.

[6] L. Savioja, J. Huopaniemi, T. Lokki, and R. Väänänen. Creating interactive virtual acoustic environments. *J. Audio Eng. Soc.*, 47(9):675–705, 1999.

[7] F. Otondo and J. H Rindel. A new method for the radiation representation of musical instruments in auralizations. *Acta Acustica united with Acustica*, 91(5):902–906, 2005.