The interaction between room and musical instruments studied by multi-channel auralization

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The directivity of musical instruments is very complicated and typically changes from one tone to the next. So, instead of measuring the average directivity, a multi-channel auralization method has been developed, which allows a highly accurate and realistic sounding auralization of musical instruments in rooms. Anechoic recordings have been made with 5 and 13 evenly distributed microphones around the musical instrument. The reproduction is made with a room acoustics simulation software using a compound source, which is in fact a number of highly directive sources, one for each of the channels in the anechoic recording. With this technique the variations in sound radiation from the musical instrument during the performance e.g. due to changes in level or movements can be reproduced with the influence of the surrounding room surfaces. Examples include a grand piano and a clarinet.

1 Introduction

Everyone playing a musical instrument or singing is aware of the fact that the acoustics of the surrounding room and the position in the room can greatly affect the sound production. Sometimes this is expressed in the way that the room is an acoustical extension of the musical instrument. However, until now the research in this interesting transition field between musical acoustics and room acoustics has been very sparse. One example where the this problem has been touched is in reference [1] where a room acoustic simulation program has been used to demonstrate objectively the influence of the instruments directional characteristics on some room acoustic parameters using measured directional characteristics for a few single tones as examples. However, a much more efficient method for this kind of research may be a new multi-channel technique, which has been developed to improve the quality of auralization in room acoustics [2].

Auralization is a technique that has developed to a state that allows many useful applications in research and in room acoustic design. The modelling of the transfer function or room impulse response from source to receiver, and the modelling of the receiver by a head related transfer function (HRTF) has been developed to a high technical level and a very satisfactory agreement with dummy head recordings in real rooms has been obtained [3].

2 Multi-channel auralization

2.1 The principle

The idea is to capture the sound as radiated from the musical instrument by using a large number of microphones in the anechoic chamber. When applied for auralization with a room acoustic simulation program, the source must be split into a number of directional sources, each representing one of the microphone channels from the recording. With this technique it is possible to listen to each part of the radiated sound and compare to the total. So, this offers a new tool for the study of the interrelation between musical instruments and the surrounding room.

2.2 Recording method

One way to capture the sound radiated by the musical instrument in different directions is to perform simultaneous anechoic recordings with microphones in different positions around and above the source [2, 4].

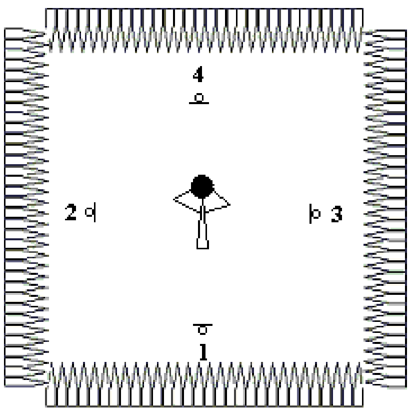

Figure 1: Anechoic recording with the multi-channel method, here shown with four microphones in the horizontal plane.

The sound recorded in different channels will contain the spatial information of the source regarding asymmetries in the instrument, movements of the performers and changes in the radiation for different tones. The principle is shown in Figure 1 in the simple case of only four channels representing the sound radiation in the frontal direction, to the left and right, and to the back.

2.3 Reproduction method

Once the multi-channel recording of the instrument has been made, each of the particular recordings registered by the microphones should be played by a particular virtual source in the auralization, according to the original position in the recordings. This can be done in a room acoustic simulation program by defining sources that have a neutral flat directional pattern within a solid angle of radiation.

Figure 2 shows an example of a setup for four-channel reproduction of a musical instrument in a room simulation with a compound source consisting of four virtual sources. The setup in this example corresponds to the anechoic recording setup in Figure 1. Each of the virtual sources in Figure 2 has a flat directional characteristic within a span of a quarter of a sphere. The new compound source will radiate in a distinctive way in each of the four directions following changes in level, movements, asymmetries and orientation of the original source, as recorded by the individual microphones.

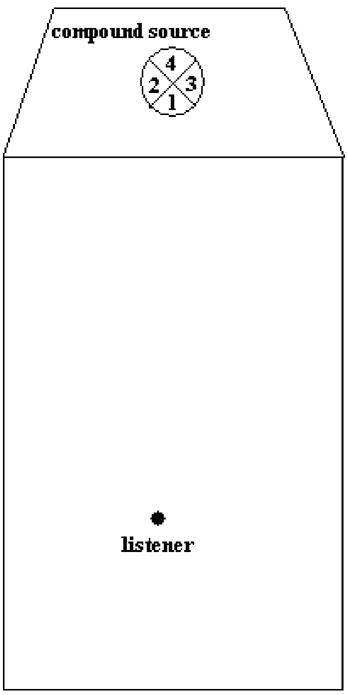

Figure 2: Room simulation with the multi-channel method. Each part of the compound source radiates into a solid angle.

In the following is described an experiment using this multi-channel auralization technique, but with five channels: The recordings are made with four microphones as in Figure 1, but in addition there is a fifth microphone above the sound source. The corresponding radiation down towards the floor has not been included in this simulation. The directivity of each of the five sources used in the room acoustic computer model is shown in Figure 3.

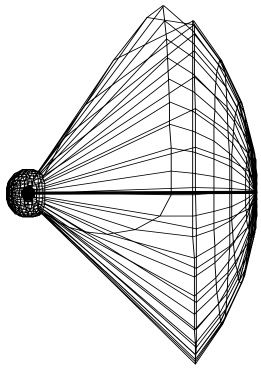

Figure 3: The directivity of a source as used for five-channel simulations.

3 The room

The room used for the auralization experiments is a chamber music concert hall, the Queens Hall in Copenhagen, which has a volume of 5,500 m^3, see Figure 4.

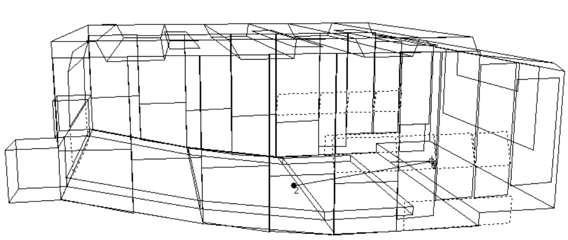

Figure 4: The concert hall used for the experiment.

Figure 5 shows a plane of the front part of the hall with source and receiver positions indicated. Three source positions are used, pos. 1 in the centre and 4 m from the back wall, poss. 2 in the centre and 2 m from the back wall, and pos. 3 shifted 6 m off the centre axis and 2 m from the back wall, see Figure 5. All source positions are 0.7 m above the stage floor, which is 0.8 m above the main floor.

Only one receiver position is used, located on the centre axis and 15 m from the back wall.

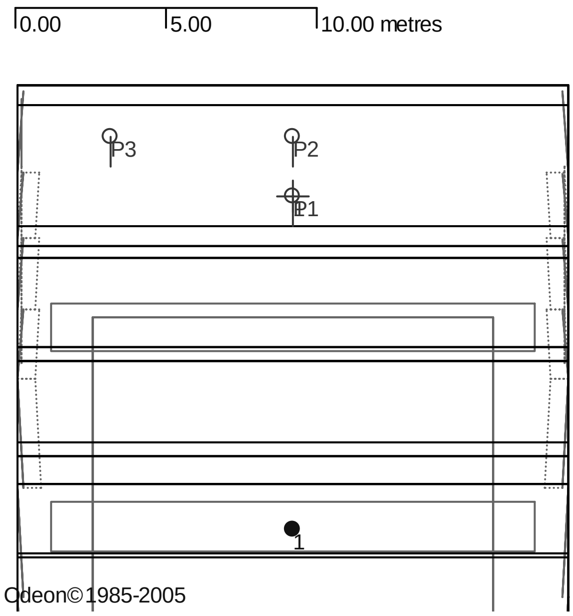

Figure 5: The three source positions and the receiver position. Only the front part of the concert hall is shown.

The experiment is carried out with two different configurations of the hall, either with a reflecting wall behind the stage or with a sound absorbing curtain behind the stage. The calculated room acoustic parameters for the three source positions and both room configurations are shown in Table 1. These calculations were made with an omni directional source.

Table 1: Room acoustic parameters for the three source positions. Average of 500 and 1000 Hz octave bands.

Hard wall	EDT (s)	G (dB)	C80 (dB)	Ts (ms)
S1 – R1	1,90	9,7	1,0	121
S2 – R1	1,96	9,1	-0,8	142
S3 – R1	2,00	9,2	0,3	127
Curtain				
S1 – R1	1,62	8,3	2,2	96
S2 – R1	1,68	7,2	0,8	110
S3 – R1	1,59	7,4	1,8	100

4 Multi-channel recordings

4.1 Recording the clarinet

The clarinet was recorded in an anechoic room using 13 microphones in a distance of 1.5 m from the centre of the source, see Figure 6. However, only the five channels representing front, right, back, left, and up were used in the investigation described in the following.

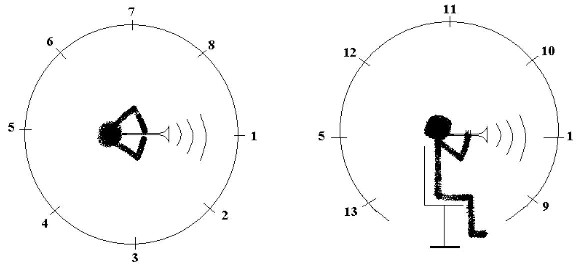

Figure 6: Positions of the 13 microphones for the recording of the clarinet. Only five of them are used here (no 1, 3, 5, 7, and 11).

4.2 Recording the piano

The piano was a grand piano of the make Bösendorfer. The lid was in open position during the recordings, which took place in a recording studio with very short reverberation time. Five microphones were used in positions as indicated in Figure 7. Microphone number 5 was in a position above the piano. The normal position of a grand piano on a stage is with the keys to the left as seen from the audience, thus microphone number 1 was in a direction 45° to the main axis from the instrument towards the audience.

The positions were chosen like this because pos. 1 is in the direction normally preferred for the microphone in studio recordings. With this choice it was also avoided to have a microphone position directly behind the player, where there is a shadow zone.

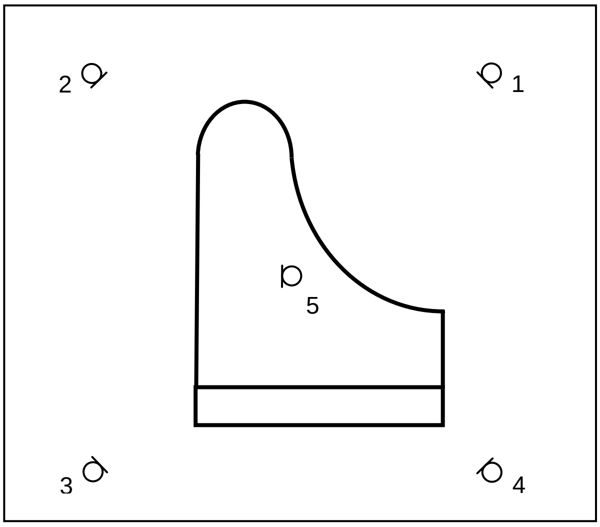

Figure 7: Positions of the five microphones for the recording of the piano.

5 Auralization results

5.1 The procedure

The simulations were made in ODEON ver. 7.1 using five-channel auralizations as described in 2.3. Three source positions and one receiver position was used, two musical instruments, each turned in two different directions, and finally the room was modelled with and without a curtain behind the stage. This makes a total of 3·1·2·2·2 = 24 simulations. Although the auralizations are meant for listening (using headphones) some objective results have been derived and will be presented below.

When the auralization files are calculated by convolving the anechoic music recording with the BRIR (Binaural Room Impulse Response), the total sound level relative to the maximum for overload is quoted. So, these sound levels are observed for the total and for each single channel representing the five different directions of sound radiation. In other words, the sound levels are the combined results of the music played, the dynamical and directional characteristics of the instrument, and the sound reflections in the room for this particular source and receiver positions.

5.2 Results for the clarinet

5.2.1 Hard wall behind the stage

The results for the clarinet in front of the hard back wall are shown in Figures 8 and 9. The strongest contribution comes from the frontal direction of the clarinet in both cases. (0° means the direction from the source to the audience parallel with the main axis of the hall). In both cases it appears that the total level in pos. 2 is low, possibly because pos. 1 is closer to the receiver and pos. 3 benefits from more reflections in the corner. Listening to the auralizations it is hard to tell the difference between the three positions, but turning the direction of the clarinet makes a audible change in timbre and it is obvious that a major contribution comes from the right side wall reflection corresponding to the 90° radiation, see Figure 9.

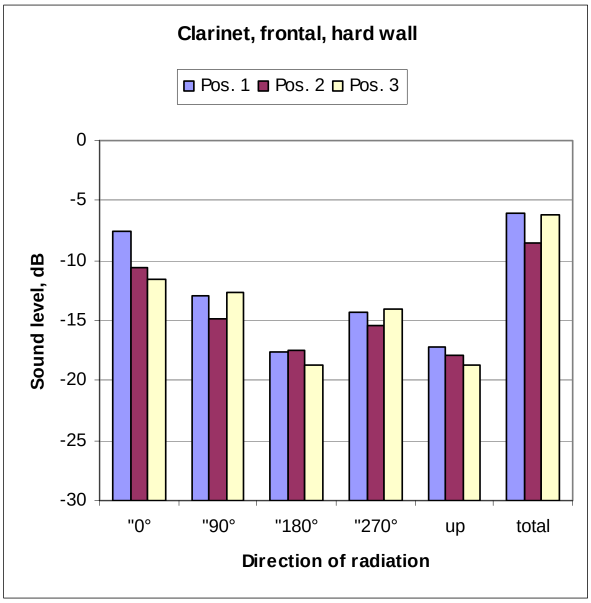

Figure 8: Relative sound level in the receiver position, clarinet frontal (pointing towards 0°).

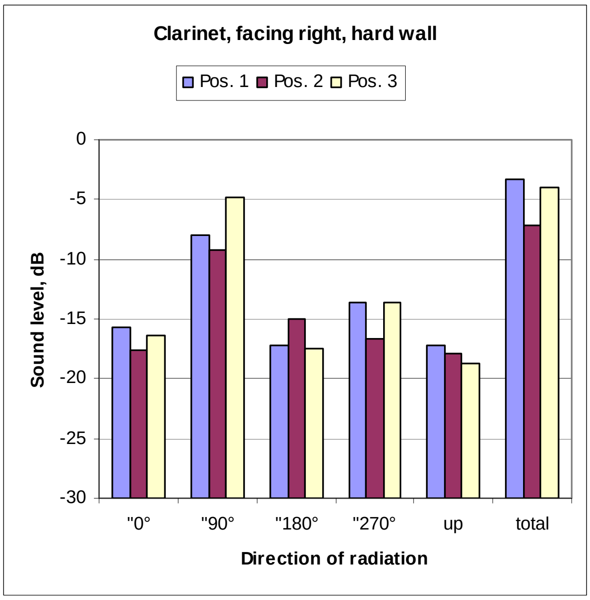

Figure 9: Relative sound level in the receiver position clarinet facing right (pointing towards 90°).

5.2.2 Absorbing curtain behind the stage

The observations in Figure 10 and 11 are similar to the previous examples. However, the 180° contribution is much weaker, because this part is radiated towards the sound absorbing curtain. The timbre is very similar with or without curtain.

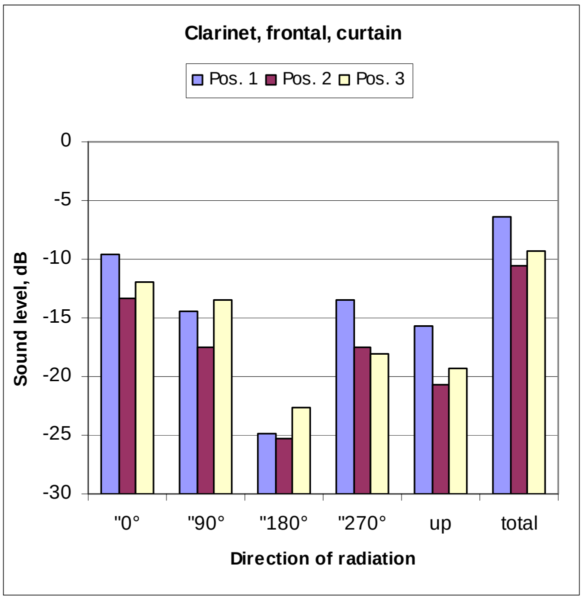

Figure 10: Relative sound level in the receiver position clarinet frontal, with curtain (pointing towards 0°).

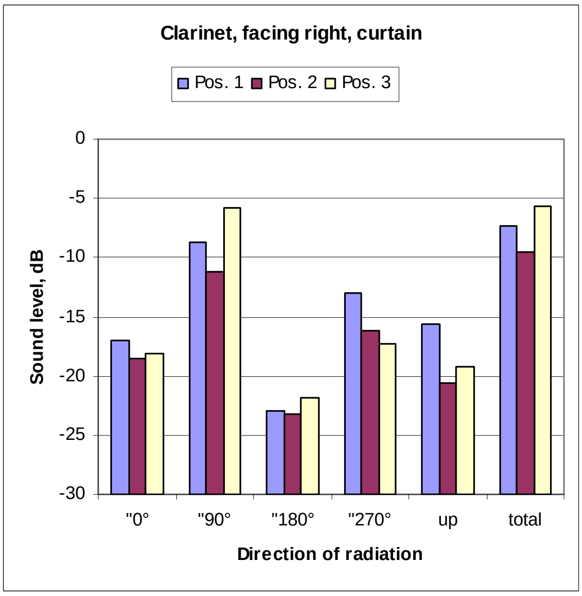

Figure 11: Relative sound level in the receiver position clarinet facing right, with curtain (pointing towards 90°).

5.3 Results for the piano

5.3.1 Hard wall behind the stage

The result for the piano in Figure 12 shows that the strongest contribution in all three positions comes from the direction + 45°, which is also the direction of the preferred microphone position for recordings. Because of the open lid reflecting sound towards the audience, very little sound is radiated backwards (± 135°).

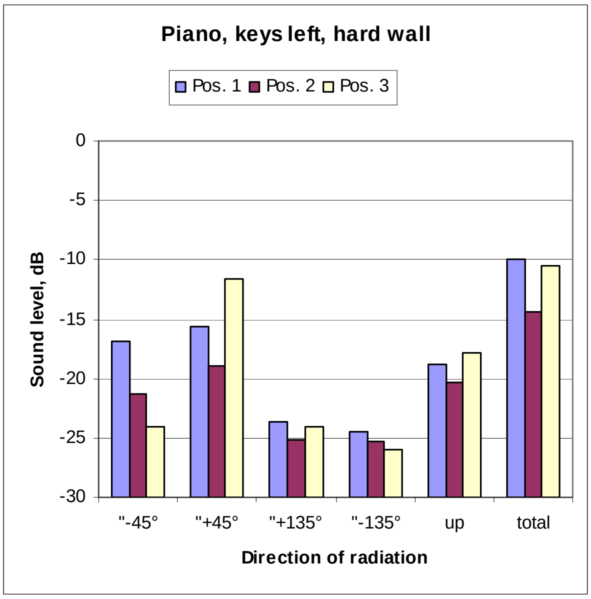

Figure 12: Relative sound level in the receiver position, piano with keys to the left.

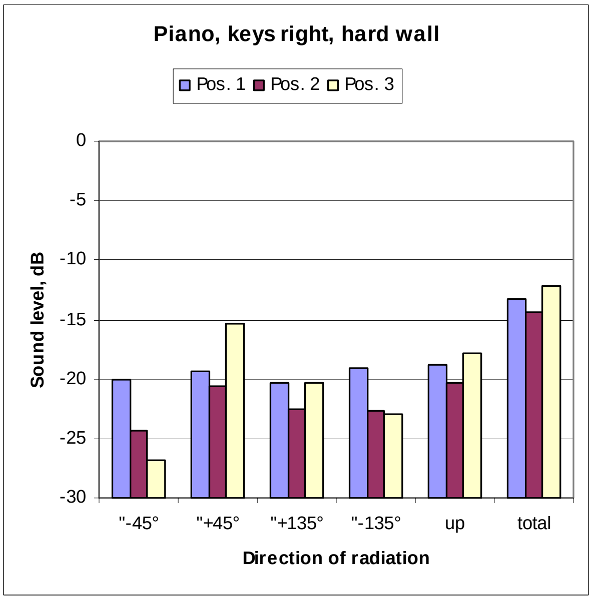

Figure 13: Relative sound level in the receiver position, piano with keys to the right.

Turning the piano 180° means that all five directions contribute approximately the same, see Figure 13. Listening to the auralizations there is a big difference in the timbre, the case in Figure 12 sounding clear and full range whereas the other case in Figure 13 sounds more dull.

5.3.2 Absorbing curtain behind the stage

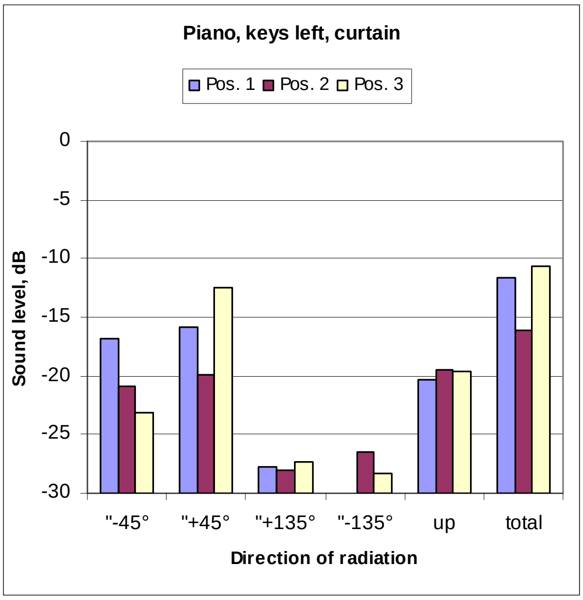

Figure 14: Relative sound level in the receiver position, piano with keys to the left, with curtain.

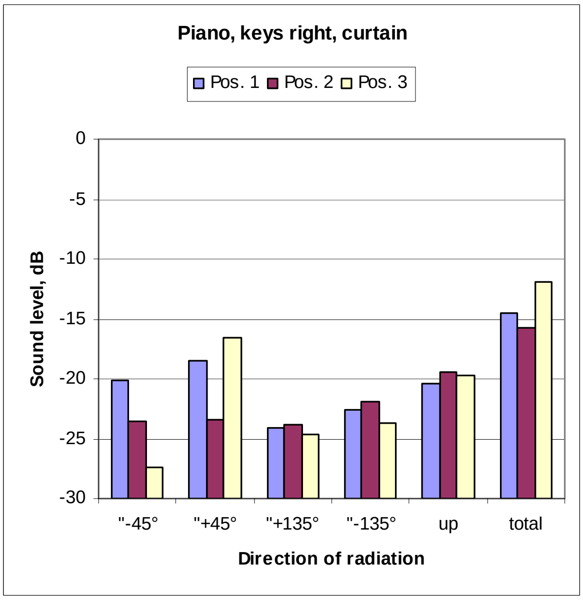

Figure 15: Relative sound level in the receiver position, piano with keys to the right, with curtain.

With the curtain in Figure 14 and 15 there are some similarities to the previous results, except that the parts radiated towards the curtain (± 135°) are weaker. In the case of Figure 14 the timbre and overall sound quality is equally good as in the case of Figure 12.

6 Conclusion

The multi-channel auralization is introduced as a new tool for the study of the acoustical interaction between room and musical instrument. Compared to the single-channel auralization this method offers improved realism in terms of the apparent source width and depth, and a more natural timbre. One reason for the improved realism may be that the directivity of sound radiation may change with time according the to the music being played.

In the present study using a clarinet and a grand piano, the following main observations could be made:

- Moving the source on the stage changed the total level, but the main effect was a change in balance between the directions of radiation causing small changes in timbre.
- Turning the source, either 90° (clarinet) or 180° (piano) had a strong influence on the balance between the directions of radiation causing audible changes in timbre.
- Introducing a sound absorbing curtain on the wall behind the stage had a clear influence on the balance between the directions of radiation, as could be expected.

References

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