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A New Method for the Radiation Representation of Musical Instruments in Auralizations

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Summary
A new method for the representation of sound sources that vary their directivity in time in auralizations is introduced. A recording method with multi-channel anechoic recordings is proposed in connection with the use of a multiple virtual source reproduction system in auralizations. Listening experiments designed to validate the quality of the reproduction method compared with a fixed directivity representation have showed that there is a clear improvement in the timbral quality of the reproduced sound. The improvement represented by the system regarding the spaciousness of sound did not prove to be significant. Further applications of the method are considered for ensembles within room auralizations as well as in the field of studio recording techniques for large instruments. A part of this article was published previously in [1].

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1. Introduction

The term "auralization" has been coined as an analogous term to visualization – it therefore names the process of rendering sound fields audible [2]. Room auralizations have as main objective a simulation as accurate as possible of the binaural listening experience at a certain location within a modelled space. As shown in previous studies, an important factor to be taken into consideration in auralization is the directional characteristics of the sound sources [3]. Musical instruments have been shown to have a complex directivity pattern, which generates a particular acoustic behaviour in a room and is not constant within the pitch-performing range [4, 5, 6]. Figure 1 shows the evolution of the directivity of a Bb clarinet for different tones in the horizontal plane measured in the 1 kHz octave band. The traditional representation of the directivity of musical instruments in auralizations assumes a fixed directivity over the whole pitch-performing range of the instruments, obtained from the average of directivity measurements [7], and a single recording for the sound to be radiated. In a recent study with room auralizations this representation has proved to be inadequate for describing the variations of the radiation for different tones played by different musical instruments [8]. Considering this as a motivation, the goal of this study has been to improve the quality of the representation of musical instruments in auralizations taking into account the changes of the radiation of the instruments in order to give a more realistic character to the sound of the source. This has been done by designing a recording and reproduction method that aims to consider to a high extent the spatial and timbristical contributions of a sound source as perceived by a listener in a room.

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2. Proposed recording and reproduction method

2.1. Multi-channel recording method

Traditionally source representation of a musical instrument in a room auralization is done by using a fixed directivity of the source and a monophonic recording. However a better representation of the spatial sonic characteristics could be achieved by considering various samples of the sound field created by the source to be used afterwards in the reproduction process. 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. The sound recorded in different tracks 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.

2.2. Reproduction method in auralizations

Once the multi-channel recordings of the instrument have been done, 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 simulations program like ODEON [9] by defining sources that have a neutral omnidirectional directivity

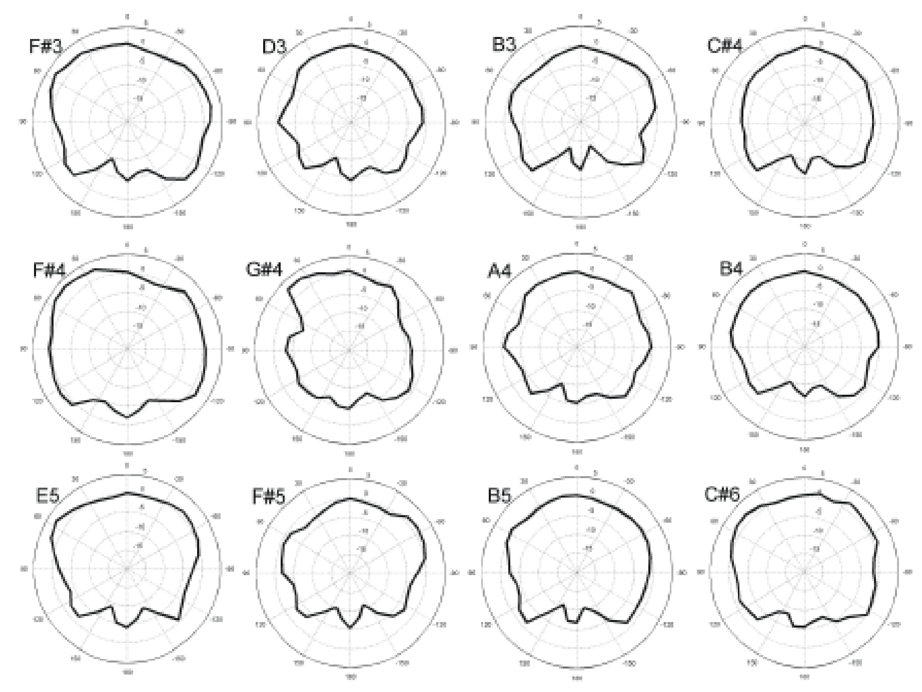


Figure 1. Evolution of the directivity of a Bb clarinet in the horizontal plane for different tones in three musical octaves measured in the 1 kHz octave band. The instrument is facing upwards in the plots.

pattern within a solid angle of radiation. Figure 2 shows an example of a four-channel anechoic recording of a musical instrument used in a room auralization with a compound source consisting of four virtual sources. Each of the virtual sources in the figure has an omnidirectional characteristic within a span of a quarter of a sphere, radiating in the direction of 0, 90, 180 and 270 degrees in the horizontal plane. The new compound source, consisting of the four virtual sources together, 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. The source will include the frecuency dependence of the simulated sources due to the filtering process done by the software for each reproduced octave for of the virtual sources. In the example shown below the reflections of the lower part and top of the musical instrument recorded have not been considered.

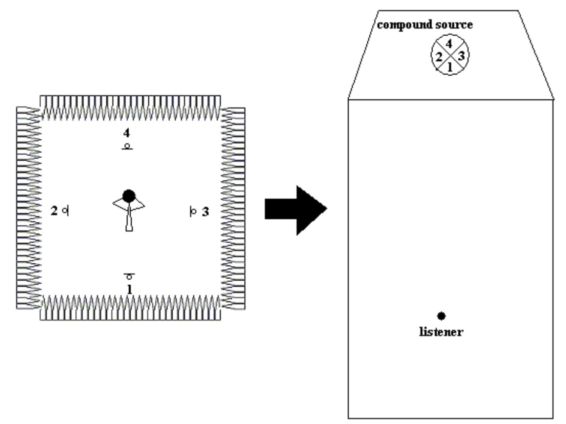


Figure 2. Horizontal view of a four-channel anechoic recording of a musical instrument and the reproduction method in a room auralization with a compound source representation using four virtual sources.

3. Validation of the method

In order to test whether the proposed multi-channel method represents an improvement as compared to the traditional fixed directivity representation that considers a monophonic recording as basis, a Bb clarinet was recorded using a multi-channel microphone array to be used in listening tests with auralizations. This instrument was chosen due to its considerable changes in radition for different tones played, as shown in Figure 1. The setup used for the measurements was a 13-channel microphone array that allowed first to use the multi-channel simultaneous recordings for the auralizations with the proposed method, and secondly to obtain the directivity measurements of the source needed for the traditional method. The traditional averaged representation was obtained for each octave band by taking samples of tones in the whole performing register of the instrument for each of the microphones, which were then filtered in the different octave bands. The filtered samples for each microphone were then averaged logarithmically for the amount of tones considered in the performing range. The resulting information for all the microphones was then assembled spatially in order to build the averaged directivity patterns in the horizontal and vertical planes. This average representation was used as a basis for the comparisons of the listening experiments. Figure 3 shows the 13-channel recording setup in the horizontal and vertical planes.

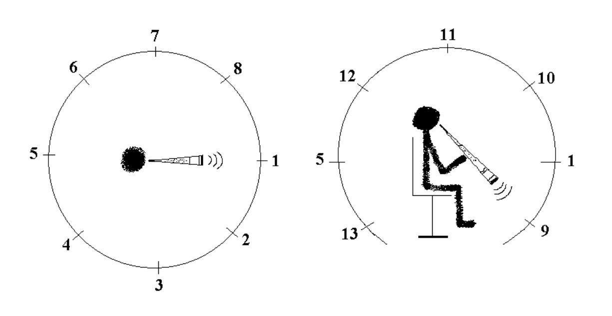


Figure 3. Setup for the multi-channel recordings and directivity measurements with 13 microphones. The left part of the figure shows the setup in the horizontal plane and the right part shows it in the vertical plane. Microphones 1 and 5 appear in both planes.

3.1. Listening Experiments

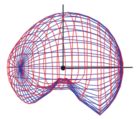
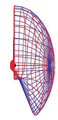
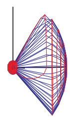
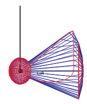
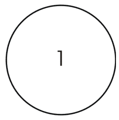
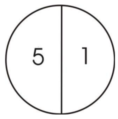
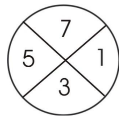
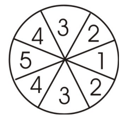
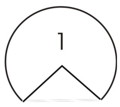
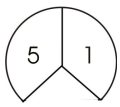
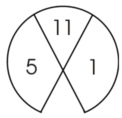
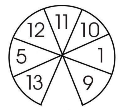
Listening experiments were designed with two main goals in mind. The first goal was to test whether the representation of the radiation in auralizations using the proposed method marks an audible improvement as compared to auralizations using the traditional representation of the radiation with a fixed averaged directivity of the clarinet. The second goal was to compare auralizations using different microphone configurations of the setup in order to test which configuration would give the best sound representation of the source. The subjects chosen for the listening experiments were five young performing musicians, students at the Royal Danish Conservatory of music in Copenhagen, and five young engineering students from the Technical University of Denmark. Two alternative-forced choice experiments were designed where the subjects had to choose one of two auralizations according to their judgment of the quality of the sound in terms of two main characteristics described below. The auralizations were created in a model of the Queen's Hall of the Royal Library of Copenhagen with the software ODEON [9] using 1282 rays per sound source, a transition order of 1, and a calculated impulse response length of 2200 ms, considering a reverberation time for the hall of 2.1 s at 1000 Hz. The position of the source in the auralizations was in the center of the stage while the listener was located at distance of 10.3 m from the source, 5 m to the right to the central axis of the hall. The subjects were presented with the pairs of auralizations through headphones Senheiser Hd 250 and asked to judge two different sound characteristics in the comparisons: perceived spaciousness of sound in the room [10] and perceived naturalness of timbre of the clarinet. These sound characteristics were chosen among others considering previous results on similar listening tests using auralizations due to the fact that these characteristics were clearly understandable by test subjects in terms of evaluation [8]. By asking about the perceived spaciousness of sound it was intended to quantify the degree to which subjects can perceive changes of the directivity of the source spatially and by asking about the naturalness of timbre it was intended to evaluate to what extent the representation of the radiation of the source affects the quality of the reproduced sound of the instrument.

Four different directivity representations were used to build the auralizations for the comparisons of the experiments, one representation using the averaged directivity of the clarinet and three representations using the proposed method with different amount of sources. The directivity representation using the averaged directivity will be called in the following analysis configuration 1, the one considering two virtual sources will be called configuration 2, the one considering five sources will be called configuration 3 and the one considering ten virtual sources will be called configuration 4. In the case of this last configuration, symmetry of the source was assumed in the horizontal plane and only the recordings of one side of the instrument were used for both sides of the representation. This was done due to limitations of the software. Table I shows the four directivity representations used in the auralizations for the listening experiments with the traditional single source representation and with the proposed method considering different amounts of virtual sources. The listening experiments were conducted automatically using a computer where the subjects were exposed to pairs of auralizations using as an excitation a short melody of 9 seconds played by the Bb clarinet, recorded anechoically using the setup of Figure 3 [11]. The subjects could listen as many times as desired to each of the auralizations in the presented pair without being able to switch samples during the playback of each sample. Each of the pairs of auralizations was judged by each participant eight times, four times in each order. After listening to the pairs of auralizations the subjects had to choose one according to the corresponding sound characteristics evaluated. In the case of the auralization with the fixed directivity the recording used for the auralization was the one recorded by microphone 1. The five auralizations were used to build pairs that were played in both orders twice, giving a total amount of 48 comparisons per subject.

3.2. Results

The results of the listening experiments were analysed using the McNemar test in order to determine the level of randomness of the data [12]. This method separates consistent responses given by test subjects from those inconsistent in order to perform a hypothesis test with the remaining consistent answers. In this case a total of 40 inputs were obtained for each comparison from ten subjects. The first and the second answers from the eight results of each comparison for each subject were tested for inconsistency and in case of being different both were discarded. The same was done with third and fourth, fifth and sixth, and seventh and eigth respectively. Considering the consistent results, the test was then used to prove the level of significance of the results considering a level of significance of 0.95. Table I shows the results of the experiments comparing the four configurations in the six possible combinations for the ten subjects.

Table I. Directivity representations for the comparisons of the listening tests. The microphone numbers in the representations are shown as related to the setup of Figure 3.

	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Type of directivity	Averaged directivity	2-channel representation	5-channel representation	10-channel representation
Number of sources	1	2	5	10
Source representation in the software for a single virtual source				
Representation in Auralizations in the Horizontal Plane				
Representation in Auralizations in the Vertical Plane				

The results of the listening test for the quality of the spaciousness in the auralizations show that the test subjects did neither have a significant preference for the system configurations, nor for the traditional representation. The audibility of the improvement of the spaciousness with different configurations of the system proved to be significant to those representations with less sources in two of the three cases.

The results of the tests for the quality of the naturalness of timbre proved that the method represents a clear improvement when compared with the averaged directivity representation; they showed in all cases a significantly higher preference for the representations with the method. When comparing the different configurations of the proposed system between them for the naturalness of timbre, the results of the listening test showed that the preferences were in two of the three cases for those configurations with more virtual sources.

3.3. Discussion of results

The analysis of the results of the listening tests will be discussed according to two types of comparisons: audibility of spaciousness and of naturalness of timbre.

The results of the comparisons between spaciousness with configuration 1 and with the rest of the configurations showed that it is difficult to assert to what degree the method can help to improve perception of the spatialisation of sound in auralizations. The listeners found it difficult to evaluate the spaciousness of the sounds and most of them seemed to have related more to the perception of the reverberation than to the spaciousness. This could be a consequence of the fact that the increase of sources proved to decrease the perceived loudness of the source, and consequently the perceived reverberation. This is due to the fact that when considering less sound sources the sound of microphone in the front of the instrument, rich in middle and high frequencies, boosts the overall level. This is also a problem that the proposed method could help to diminish, being quite critical of the traditional method where one monophonic recording done in the front of the instrument is assumed as representative of the sound of the whole radiation sphere of the instrument. This behaviour would be consistent with results of a previous study with auralizations [7]. When comparing the different configurations with the proposed system, the results proved to have a similar behaviour.

The second comparison of the experiments, audibility of naturalness of timbre, showed a significantly higher preference for the representations with the system when compared with the traditional method in all the cases. The system proved to make more reliable the sound reproduction in auralizations increasing the quality of the sound of the source. The problem of the colourations that arise using a single recording of the traditional method does not seem to have been perceived by the test subjects, who rated the sounds from the system as better than those with the traditional method in all the cases. When comparing the different configurations within the system the subjects seemed to notice an improvement of the quality of the naturalness of timbre with the increase of the amount of sources used in the system. This was true for two of the three cases.

4. Conclusions

The evaluation of the system has shown that there is a clear improvement in the audibility of the naturalness of timbre in auralizations with the proposed method. The results of the evaluation of the system as to spaciousness did not prove to be consistent. The listeners seemed to have difficulty in perceiving the spaciousness and seemed to relate more to reverberation, as shown in a previous similar study with auralizations.

Table II. Results of the listening experiments with the rates of selections between the six combinations of compared configurations and significant results from a total of 40 inputs for each comparison.

Configuration Comparison	1 v/s 2		1 v/s 3		1 v/s 4		2 v/s 3		2 v/s 4		3 v/s 4	
Spaciousness	1	2	1	3	1	4	2	3	2	4	3	4
	20	14	20	14	24	12	16	12	26	10	24	8
Consistent answers	34		34		36		28		36		32	
Critical values	22		22		23		18		23		21	
Significance	No		No		Yes		No		Yes		Yes	
Naturalness of Timbre	1	2	1	3	1	4	2	3	2	4	3	4
	4	28	0	24	2	38	16	8	2	26	2	26
Consistent answers	32		24		40		24		28		28	
Critical values		21		16		25	16			18		18
Significance		Yes		Yes		Yes	Yes			Yes		Yes

Considering the results of the listening experiments used to validate the proposed method, it can be concluded that the method represents an improvement in terms of the quality of the reproduced sound. That is, this method gives a representation which is more faithfull to the sound of the source when perceived by a listener than traditional auralization methods using single monophonic recording and a fixed representation of the directivity of the source. Therefore the potential of this method relies on the use of the original sounds radiated by the instruments instead of a theoretical approach to their radiation. It can be inferred that tonal directional instruments are more suitable for the use of this method than instruments having wideband signals with transients and a directivity closer to that of an omnidirectional source. The quality of this method when reproducing sound sources that are less directional also remains to be studied.

As a way to make the method more efficient in terms of measurements and computational effort further studies could consider different microphone setups with less microphones asuming symmetries in the vertical axis as done in this case for the horizontal axis.

Applications of the proposed method may lie among others in the representation of sound sources that are difficult to characterise with a single directivity pattern such as groups of instruments. Other applications could also be considered in the field of studio sounds recording with the use of the proposed recording technique to improve the richness of recordings of pianos or other large instruments difficult to characterise with the traditional stereo techniques.

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