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Objective and Subjective Evaluation of the Use of Directional Sound Sources in Auralizations

Lily M. Wang
University of Nebraska - Lincoln, lwang4@unl.edu

Michelle C Vigeant
University of Nebraska - Lincoln

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Lily M. Wang and Michelle C. Vigeant

Architectural Engineering Program
University of Nebraska – Lincoln, Nebraska, USA
LWang4@UNL.edu

Abstract

Omni-directional sources are often used in room acoustic computer simulations, as opposed to directional sources, since measured directivity data are quite limited and difficult to obtain. The purpose of this study is to investigate the objective and subjective significance of adding more complex directivity to the sources used in computer simulations and auralizations. A simple hall was used as the modelled space in the software program ODEON. Three source positions on stage and three receiver audience positions were chosen. Impulse responses (IRs) were calculated for the nine source/receiver combinations, using (a) an omni-directional source, (b) a highly directional source beaming in a sixteenth-tant of a sphere, and (c) three realistic sources: piano, singing voice and violin. The directivity data for the three realistic sources, obtained from the Physikalisch-Technischen Bundesanstalt website, were available in octave bands from 1 kHz – 4 kHz for the piano and violin, and from 125 Hz – 4 kHz for the singing voice. The objective measures evaluated were Sound Pressure Level (SPL), Reverberation Time (T60) and Clarity Index (C80). In general, there is at least 5% difference in T60 data between the omni-directional source and the realistic directional ones. Differences in SPL and C80 are more irregular across frequency bands and appear to be more apparent for sources with higher directivity index. For select source/receiver combinations, the IRs resulting from each source directivity have been convolved with anechoic musical recordings of piano, singing and violin to produce auralizations. Subjective testing revealed a noticeable difference between the omni-directional and the sixteenth-tant sources, but not with the realistic sources.

1. Introduction

Sound sources are generally modelled as omni-directional sources in auralization programs, as accurately measured directivity data is difficult and time-consuming to obtain. Dalenbäck did previous work that looked at subjective perception of changing the directivity of the sound source in auralizations [1]. The source used in this study was male speech; however, the study did not isolate directivity. Dalenbäck concluded that the change in the directivity of the source was perceived by the test subjects. Research by Prince and Talaske confirmed that source directivities are important to consider for auralizations [2]; their research did not include auralization software, though.

Giron also studied the subjective effects of changing sound directivity [3]. The research involved modelling a sound source using inverse spherical harmonics transforms (ISHT) as the solution to the homogeneous Helmholtz equation. The sound source modelled was a speech signal using increasing orders of ISHT. The subjects were able to differentiate between signals of different directivities. However, the sample size was quite small and could not be statistically verified.

The present study investigates the objective and subjective significance of adding more accurate directivities to the sources used in auralizations.

2. Experimental method

2.1. Room acoustic modeling software

ODEON Room Acoustics Software, distributed by Brüel and Kjær and developed at the Technical University of Denmark, was the program used for all computer calculations and simulations.

2.2. Room geometry and materials

Fig. 1 illustrates the chosen room geometry: a very simply shaped auditorium. The maximum dimensions of the space are 22 m in length, 16 m in width and 10 meters in height. The overall volume of the space is approximately 3000 m^3.

The materials were chosen based on the model of a simple hall. The stage floor is a wooden floor on joists, with an average mid-frequency (500 Hz, 1 kHz and 2 kHz) absorption coefficient, α_{mid} = 0.08. The audience area is composed of lightly upholstered seats (α_{mid} = 0.8), the stage and audience ceiling is wood facing on frame over a 50 mm cavity (α_{mid} = 0.09), and the remaining walls are made of plaster (α_{mid} = 0.05). The stage floor, audience area and rear wall were assigned a scattering coefficient of 0.7, while the remaining surfaces were assigned a value of 0.1.

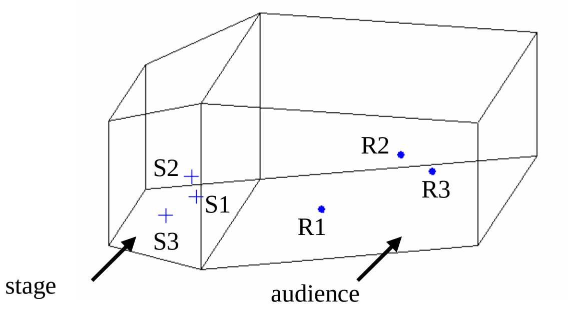

Figure 1: Room geometry

2.3. Source and receiver locations

Three source and three receiver locations were chosen. The source positions are represented by "+" in Fig. 1, and were distributed on the stage at representative performing positions: S1, front and center; S2, to the right and back from S1; and S3, to the left and back from S1. The three receiver locations were distributed in the audience seating area, and are shown as solid dots in Fig. 1: R1, "front-left"; R2, "mid-right"; and R3, "back-left". The purpose of using more than one source/receiver combination was to minimize any irregularities occurring at a specific location. Nine distinct source/receiver combinations were created and used for the objective simulations.

2.4. Sources

2.4.1. Omni-directional source

An omni-directional source radiates sound equally in all directions; thus, visual representation of its directivity pattern appears as a sphere.

Since ODEON requires octave band directivity input from 63 Hz to 8 kHz, the omni-directional source was set to the same spherical pattern for all eight bands.

2.4.2. Directional sources

Three directional sources were chosen for the study: piano, singing voice and violin. The directivity data were obtained from the Physikalisch-Technische Bundesanstalt (PTB) website [4], which incorporated Jürgen Meyer's far-field directivity measurements [5]. For both the piano and violin, directivity data were only available for 1 kHz, 2 kHz and 4 kHz. For the remaining bands, the directivity pattern was set to omni-directional. Figs. 2 and 3 illustrate the piano and violin directivities, respectively, for 1 kHz – quite different from an omni-directional source. The directional characteristics of the singing voice are more similar to a sphere, as shown in Fig. 4. Directivity data for the singing voice were available from 125 Hz to 4 kHz. Again, the remaining bands were set to omni-directional. It is desirable to have directivity data for all frequency bands, but unfortunately such complete data sets were not available.

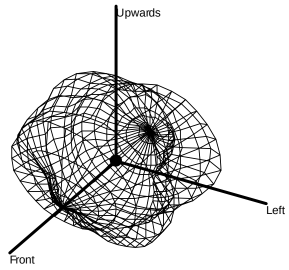

Figure 2: Piano at 1 kHz

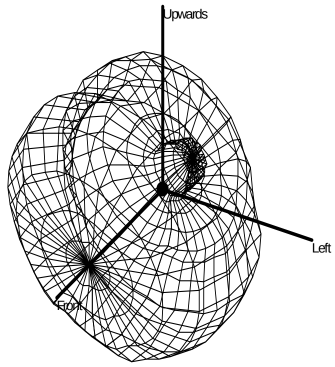

Figure 3: Violin at 1 kHz

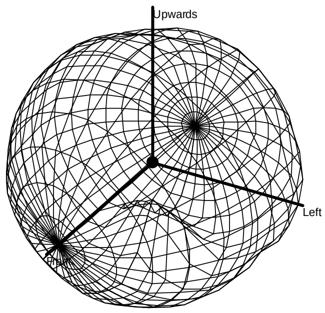

Figure 4: Singing at 1 kHz

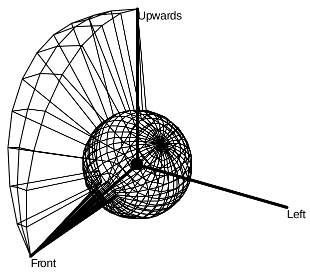

Figure 5: Sixteenth-tant directional source at 1 kHz

2.4.3. "Sixteenth-tant" directional sources

A second set of directional sources with narrowly beaming directivity patterns were created (Fig. 5) to compare against the omni-directional sources. The beaming source has one sixteenth of its sphere set to be 10 dB louder than the rest of its directivity pattern. This directionality was applied to all eight octave bands.

2.5. Source/receiver combinations and ODEON calculations

Binaural room impulse responses (BRIR's) were calculated for each of the nine source/receiver combinations for the five sources: omni-directional, piano, singing voice, violin, and the sixteenth-tant. In total there were 45 calculated BRIR's. The parameters used for comparison between the omni-directional and the directional sources were sound pressure level (SPL), reverberation time (T60) and the 80 ms clarity ratio (C80). The source/receiver combinations that resulted in the most significant differences in the objective data were used subsequently for auralizations.

3. Discussion

3.1. Omni versus realistic directional sources

The subjective limen or just noticeable difference (JND) for SPL was taken to be 3 dB. Averaged across all source/receiver combinations at individual frequencies, none of the realistic sources SPL's differed by more than 3 dB from the omni source, with the exception of the singing voice at 4 kHz (Fig. 6). The differences in C80 between the realistic and omni sources were also below the JND of 1 dB for clarity, except for the piano source at 4 kHz (Fig. 7). The exceptions of the singing voice and piano at 4 kHz are likely due to the high directivity indexes of the sources at this frequency.

The reverberation time results differed around the JND of 5% for T60 between omni and realistic sources (Fig. 8). The average values for the piano were greater than 5% for 1 kHz to 4 kHz, while the values for the singing voice were only above the JND of 5% at 1 kHz and almost at 4 kHz. The difference in the violin T60's was very close to 5% at the three frequency bands.

3.2. Omni versus sixteenthant directional sources

SPL results from the sixteenth-tant source are not objectively different from the omni-directional source. The average difference in SPL across all frequencies bands from 63 Hz to 8 kHz and across all source/receiver positions was 1.5 dB, below the JND. The average difference in T60 was 4.8%, which is borderline detectable. The most significant differences arose between the omni-directional and sixteenth-tant clarity values. The average difference in C80 was 1.6 dB, which is well above the JND of 1 dB.

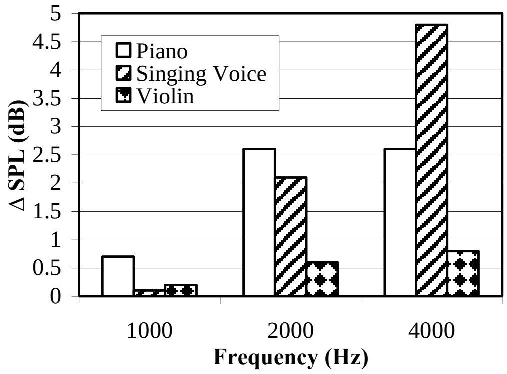

Figure 6: Difference in SPL between omni-directional and directional sources

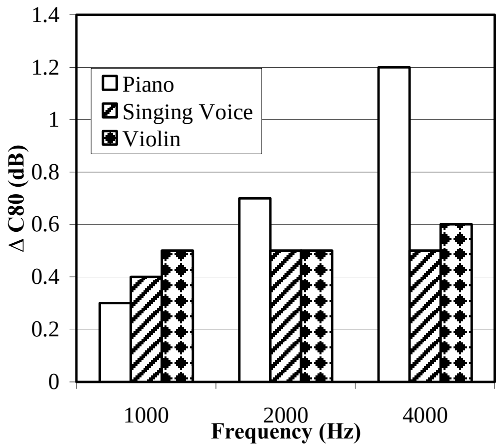

Figure 7: Difference in C80 between omni-directional and directional sources

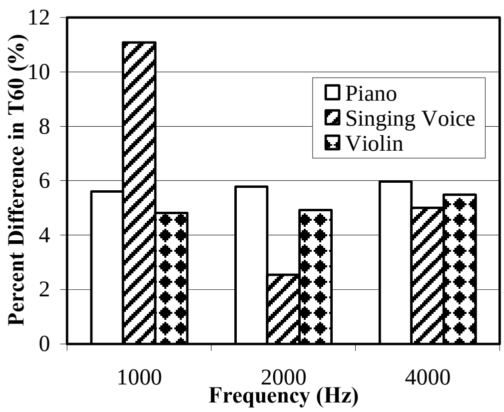

Figure 8: Percent difference in T60 between omni-directional and directional sources

4. Auralization and subjective testing

4.1. Choice of source/receiver combinations

The choice of which source/receiver combinations to use for the auralizations was based on T60 differences between the omni-directional and realistic directional sources. The largest average difference across the three frequency bands (1 kHz, 2 kHz, 4 kHz) was 12%. This value occurred for the piano source with S1/R3, and for the singing voice with S3/R2. Thus, the omni, realistic, and sixteenth-tant directional BRIR's for these two source/receiver combinations were convolved with a short dry musical recording of the directional sources: solo piano, singer and violin. A third source/receiver position of S1/R1 was chosen for use in practice trials.

4.2. Auralizations

A total of 27 auralizations were created. Each subject listened to two sets of 21 paired comparisons, which contained seven subsets of three pairs each. The three pairs included (1) the omni-directional versus directional tracks, (2) repeated in the opposite order, and (3) either a control of omni-omni or directional-directional. The order of the subsets and pairs was completely randomized. Practice trials were utilized at the beginning of each set without the subjects' knowledge to better train them and to allow their results to reach an asymptotic level [6].

For each paired comparison, the subject was allowed to listen to both tracks as many times as desired. The subject then had to answer the following question: "Do the tracks sound the same or different?" After finishing the first set of 21, the subject took a five to ten minute break before completing the second set. The testing lasted approximately one and a half hours per listener.

4.3. Subject group

There were a total of 28 subjects, eighteen of which were male. All subjects had hearing thresholds of 25 dB hearing level or lower and a minimum three years of classical musical training. Musicians were chosen, since the authors postulated that they would have better musically trained ears than the average person.

5. Auralization results

Subjects were given six controls in each set. For their results to be considered valid, the subjects had to get at least four out of the six controls correct. This criterion significantly reduced the amount of valid data. Out of 28 subjects, only eight passed the control test for the realistic set and nine passed for the beaming set.

From the valid data group, the average number of responses that stated that the omni-directional and the realistic directional tracks sounded different was 46%, with a standard deviation of 39%. In contrast, the average number of responses that the omni-directional and sixteenth-tant directional tracks sounded different was 79%, with a standard deviation of 12%. The results are likely better for the sixteenth-tant set, because the directionality was changed for all frequency bands instead of only three or six bands for the realistic sources. Additionally, the beaming nature of the sixteenth-tant source may have produced a significantly different impulse response from the omni-directional source, as compared to the realistic sources.

6. Conclusions

Objective measures show a difference between the omni-directional sources and the directional sources. The most significant difference between the omni-directional source and the realistic directional sources occurs for T60, with average differences of approximately 5%. The differences in T60 between the omni-directional and the sixteenth-tant directional were below 5%; however, their average difference in clarity was well above the subjective limen of 1.0 dB, at a value of 1.6 dB.

Subjectively, the differences between the omni-directional and realistic directional sources were not perceived at a significant value. Differences between the omni-directional and the sixteenth-tant directional were detectable, though, as 32% of the subjects could hear a difference approximately 80% of the time.

7. References

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