Visualizing diffraction for educational purposes

Ville Pulkki[1] *and Tapio Lokki*[2]

[1]Laboratory of Acoustics and Audio Signal Processing
[2]Telecommunications Software and Multimedia Laboratory
Helsinki University of Technology
Ville.Pulkki@hut.fi

Abstract

The acoustics of a room can be visualized by plotting image sources at the positions where they occur. Recently, the image-source method has been extended to include edge diffraction, and a visualization technique for image sources including diffraction (edge image sources) has been presented. Visualization is performed in analogous fashion with visualization of mirror image sources. The receiver-relative direction and distance correspond to the direction from which the sound reaches a receiver and the length of the propagation path, respectively. First-order edge diffraction is presented as curved line sources, and second-order edge diffraction as surface sources. As examples, first-order diffraction in a stage-house, and second-order diffraction around a loudspeaker enclosure are visualized.

1. Introduction

Visualization of a sound field is valuable in the design of acoustics and for educational purposes. For visualization, the sound field has to be either measured or modeled. Because measurement of three-dimensional (3-D) sound fields is in many cases impracticable, an alternative, the modeling of an acoustic space, is an attractive approach. Acoustics can be modeled with different techniques. In some cases, the wave equation can be solved exactly; in others, it can be approximated numerically using finite or boundary element methods [1]. These methods simulate a 3-D sound field inside a modeled space. Direct visualization of a 3-D sound field does not give a priori knowledge of contributions of different types of interactions between sound waves and room geometry, such as specular reflections or edge diffractions.

In ray tracing and image-source methods, sound is considered to propagate only as rays, and the wave phenomena of sound are neglected. In ray tracing, the acoustics may be visualized by plotting sound rays, as done by Kuttruff [2]. With the image-source method, reflections from surfaces are represented with mirror image sources. The method gives an exact solution for the wave equation only in a rectangular room with rigid surfaces [3]. The concept of image sources has also proven fruitful in visualization. By illustrating the image sources around the studied geometry, the spatial and temporal distributions of reflections are clearly seen.

The image-source method was applied to complex geometries earlier [4], but it neglected edge diffraction. Recently, however, diffraction for edges between rigid surfaces has been included by Svensson et. al [5]. In the approximation, a diffractive edge is divided into small elements through which sound rays travel from a source to a receiver, and the radiation characteristics of each element are computed. The resulting impulse response in the receiver position is a sum of the unit impulses radiated. This makes the image-source method applicable for all geometries that include rigid surfaces. Recently, a visualization method for edge diffraction in image-source method has been suggested [6], and it is reviewed in this paper.

2. Edge diffraction with the image-source method

This work has been conducted as an extension to the DIVA (Digital Interactive Virtual Acoustics) project [7]. Edge diffraction was recently implemented in the image-source method included in the DIVA software [8] based on Svensson's software to compute impulse responses for diffractive edges [9]. In the implementation, edge diffraction is treated as a new way to create image sources. Each image source can contain any number of reflections and maximally two diffractions in any order. Image sources are named differently based on whether they contain diffracted components. A mirror image source denotes an image source that includes only specular reflections. On the other hand, an edge image source denotes an image source with at least one diffraction and any number of specular reflections. The order of an image source is the order of reflections added to the order of diffractions.

Image sources may be formed by any permutation of the reflections from different surfaces and diffractions from different edges. However, in complex geometries, most of them are not visible to a receiver, i.e., there is at least one obstacle on the propagation path of sound. Visibility of a mirror image source is tested by computing the propagation path and confirming that there are no obstacles on the path, and by assuring that a mirrored image source is visible through the last reflection surface. An edge image source may be partly visible, thus a visibility check should be done for all points of the edge. In practice, an edge is divided into a finite number of fractions, for which the visibility is checked.

3. Visualization of edge image sources

A mirror image of a point-like sound source is visualized as a point to the receiver-relative direction, which corresponds to the direction from where the sound reaches the receiver. In addition, the distance between the receiver and the mirror image source corresponds to the length of the total sound propagation path. The point may be visualized as a box or sphere, the volume and color of which may correspond to radiation magnitude. These visualization principles are now extended for edge diffraction as well.

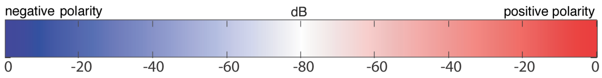

Figure 1: *The color scale used in illustrations. The radiation magnitudes of sound or image sources in an illustration are scaled with the largest absolute value in that case.*

3.1. First-order diffraction

When a single diffractive edge is presented in the sound propagation path, an image source can no longer be visualized as a point source but rather as a line source. A line source consists of an infinite number of point sources arranged on a line. Each point source is then visualized as a mirror image source. This, in turn, leads to a simple procedure to visualize an edge image source. The edge corresponding to the edge image source is divided into small fractions. The receiver-relative direction-of-arrival and propagation path length are computed for visualizing each fraction, which yields positional information for each one. The edge image source is visualized by connecting adjacent fractions with a line. Furthermore, the radiation magnitude of each fraction can be visualized by replacing the line with a cylinder, whose volume corresponds to radiation magnitude. In each illustration, the volumes of boxes presenting direct sound and mirror image sources and the volumes of cylinders presenting first-order edge image sources can be used to compare radiation magnitudes arriving at the receiver position from the sources.

The cylinders may be colored as well. In this study, color for each fraction is computed by dividing the radiation magnitude with the surface area of the cylinder fraction. The color is computed similarly with other types of image sources and with sound sources. The image sources may have different polarities and largely varying magnitudes. Thus a blue-white-red color scale using decibels, shown in Fig. 1, was chosen since it intuitively presents positive and negative values and shows a large dynamic scale. Radiation magnitudes of sources and image sources in an illustration are scaled with the largest absolute value found. In each illustration, the blue or red color denotes the polarity, and the magnitude of color denotes the amount of radiation in decibels compared to largest radiation magnitude in that case.

First-order edge image sources for a first-order edge image source occurring on one edge of a plane are illustrated schematically in Fig. 2(a) and more precisely in Fig. 3, where it can be seen that the radiation magnitude and polarity indeed depend on the position of the receiver and source. It is interesting to note in Fig. 3 that, although cases *Receiver near* and *Source near* are reciprocal, their visualizations are different. Different visualizations are because the sound reaches the receiver from a wider angle when it is near the edge. If a response were measured with a directive microphone, e.g., a dummy head, the responses would be different, which motivates different visualization for reciprocal cases in this example.

In Fig. 4(a), first-order mirror and edge image sources occurring in a unenclosed stage-house are presented. The edges that generate diffraction are the front corners of the stage and the corners between the stage walls and the back wall, as well as the corners between the stage walls and the ceiling. It can be seen that the magnitude of diffraction varies prominently with the position on the edge. In Fig. 4(b) first- to third-order image sources are shown for a simple room including a stage-house.

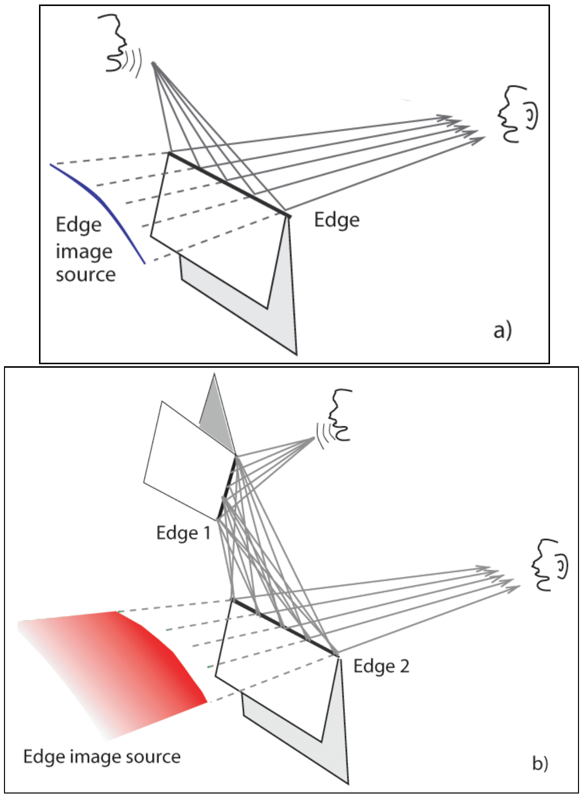

Figure 2: *Schematic visualizations of a) first- and b) second-order edge image sources.*

The number of edge image sources is high, and they are concentrated around the stage. Diffractive edges emanate sound in most directions. This enables a multitude of possible propagation paths. If image sources farther than 60 meters were also visualized, there would be more of them in the back of the room, but fewer than in the front. It is noteworthy that there are lots of edge image sources on lateral directions of the stage-house. Eventually the diffraction from edges between the room and the stage are reflected by side walls, which causes diffracted sound to traverse side to side.

3.2. Second-order diffraction

In second-order diffraction there exist two edges within a propagation path of sound. Each part of a second edge receives a response from each part of a first edge. At different positions of the second edge, the first-order response has a variable temporal length due to geometry. The response that a small fraction of the second edge emits naturally has the same temporal length as the response coming from the first edge to that fraction. If such an image source is replaced with point sources, the sources should be arranged in a two-dimensional fashion to present the temporal length of each point of the edge image source as well. An edge image source thus consists of a large number of point sources arranged on a planar surface. For visualization, point sources are replaced with pieces of surface, composing a continuous planar surface, as shown in Fig. 2(b). For visualizing the magnitude, each piece can be colored. In this case, color is computed by dividing the radiation magnitude by the area of each surface piece. However, unlike with first-order edge image sources, using the volume (thickness) of

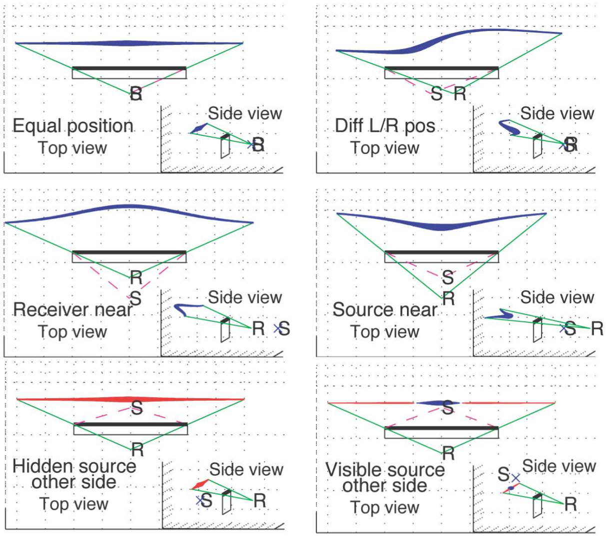

Figure 3: *Visualized first-order edge image sources. A thick line (of a rigid plate) denotes a diffracting edge, the curved cylinder is the visualization of an edge image source, the volume and color of it corresponds to radiation magnitude. R and S denote receiver and source, respectively.*

surface for visualization is impractical. In the following example, the proposed visualization method is illustrated with a loudspeaker enclosure. Edge image sources of different order can be compared with colors, although, in all cases, the radiation magnitude of second-order image sources has been scaled up, since otherwise their visualizations would be too faint.

A sound wave emitted by a loudspeaker element is diffracted from the edges of the loudspeaker enclosure. In our example, shown in Fig. 5, the emitting element, i.e., the sound source *S* is in the upper left corner of the front panel, and the receiver *R* is one meter in front of the loudspeaker. Edge image sources for a loudspeaker enclosure are visualized for all edges in Fig. 5 with two sample receiver positions. The response has been computed by searching image sources with the DIVA software [7, 8], and by modeling diffraction with Svensson's toolbox [9].

An interesting behavior is seen when direct sound has just been shadowed behind the corner of the enclosure. In Fig. 5(b) the first-order edge image source of edge 2 has a very sharp peak in the position that corresponds to the shortest wave propagation path. Additionally, strong stripes of a different form are present in second-order edge image sources, when compared with visualizations in Fig. 5(a). Edge 2 diffracts the diffracted sound arriving from edges 1, 3, and 4 in a similar manner as the direct sound. This causes the shortest paths from each position of edges 1, 3, and 4 via edge 2 to receiver to transmit more energy than longer paths, which produces the differently-formed stripes. More visualizations are presented in [6] and in [10].

4. Conclusion

A technique to visualize edge diffraction with the image-source method is reviewed. First-order edge diffraction is presented as curved line sources, and second-order edge diffraction as surface sources. The visualizations are computed so that the receiver-relative direction and distance correspond to the direction from which the sound reaches a receiver and the length of the propagation path, respectively. The magnitude of diffraction is presented with line thickness and/or color. As an example, visualizations of diffractions from a stage-house and from loudspeaker edges are shown. Visualizations intuitively show the behavior of diffraction in the presented cases.

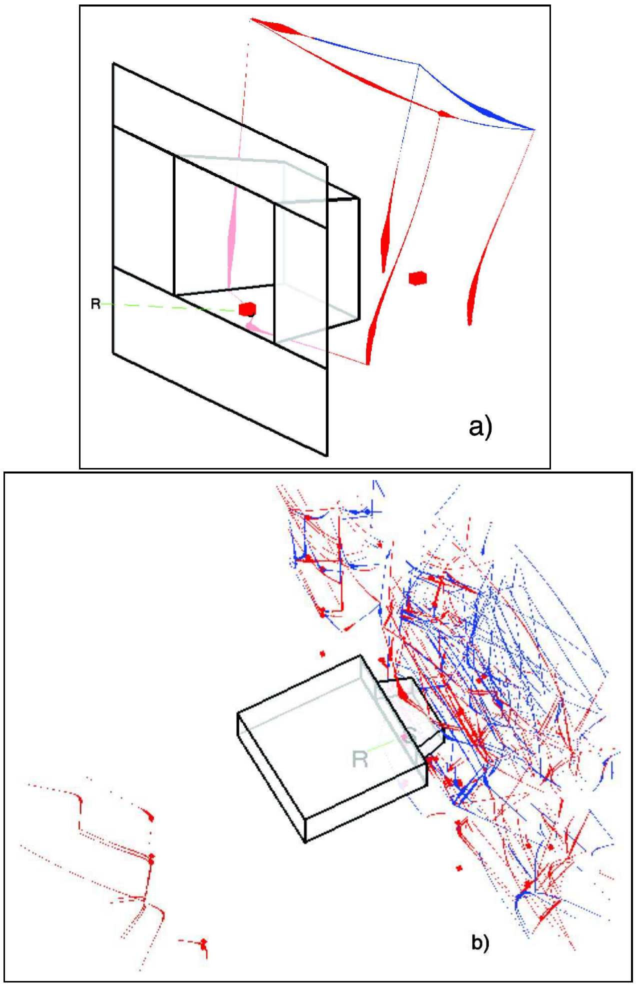

Figure 4: *a) First-order image sources in a stage-house. b) First- to third-order image sources that contain maximally one diffraction and are no farther than 60 m from the receiver in an enclosed stage-house. Mirror image sources are denoted with squares and edge image sources with cylinders. The volumes and colors (scale in Fig. 1) of mirror and edge sources are proportional to the magnitude of radiation. Animated versions of these figures are presented on a web page [10].*

5. Acknowledgment

This work has received funding from the Academy of Finland (#101339).

6. References

[1] A. Pietrzyk, "Computer modeling of the sound field in small rooms," in *Proc. AES 15th Int. Conf. on Audio, Acoustics & Small Spaces*, Copenhagen, Denmark, Oct. 31 - Nov. 2 1998, pp. 24–31.

[2] H. Kuttruff, *Room Acoustics*, 4th ed. London: E & FN Spon Press, 2000.

[3] J. B. Allen and D. A. Berkley, "Image method for efficiently simulating small-room acoustics," *J. Acous. Soc. Am.*, vol. 65, no. 4, pp. 943–950, 1979.

[4] J. Borish, "Extension of the image model to arbitrary polyhedra," *J. Acous. Soc. Am.*, vol. 75, no. 6, pp. 1827–1836, 1984.

[5] U. P. Svensson, R. I. Fred, and J. Vanderkooy, "Analytic secondary source model of edge diffraction impulse responses," *J. Acous. Soc. Am.*, vol. 106, no. 5, pp. 2331–2344, 1999.

[6] V. Pulkki and T. Lokki, "Visualization of edge diffraction," *Acoustics Research Letters Online*, vol. 4, no. 4, pp. 118–123, Oct 2003.

[7] L. Savioja, J. Huopaniemi, T. Lokki, and R. Väänänen, "Creating interactive virtual acoustic environments," *J. Aud. Eng. Soc.*, vol. 47, no. 9, pp. 675–705, Sept. 1999.

[8] V. Pulkki, T. Lokki, and L. Savioja, "Implementation and visualization of edge diffraction with image-source method," in *the 112nd Audio Engineering Society (AES) Convention*, Munich, Germany, May 10-13 2002, preprint no. 5603.

[9] U. P. Svensson, "Edge diffraction toolbox," http://www.tele.ntnu.no/users/svensson/Matlab.html, 1999.

[10] V. Pulkki, "Visual diffraction," http://www.acoustics.hut.fi/~ville/diffrvisual, 2003.

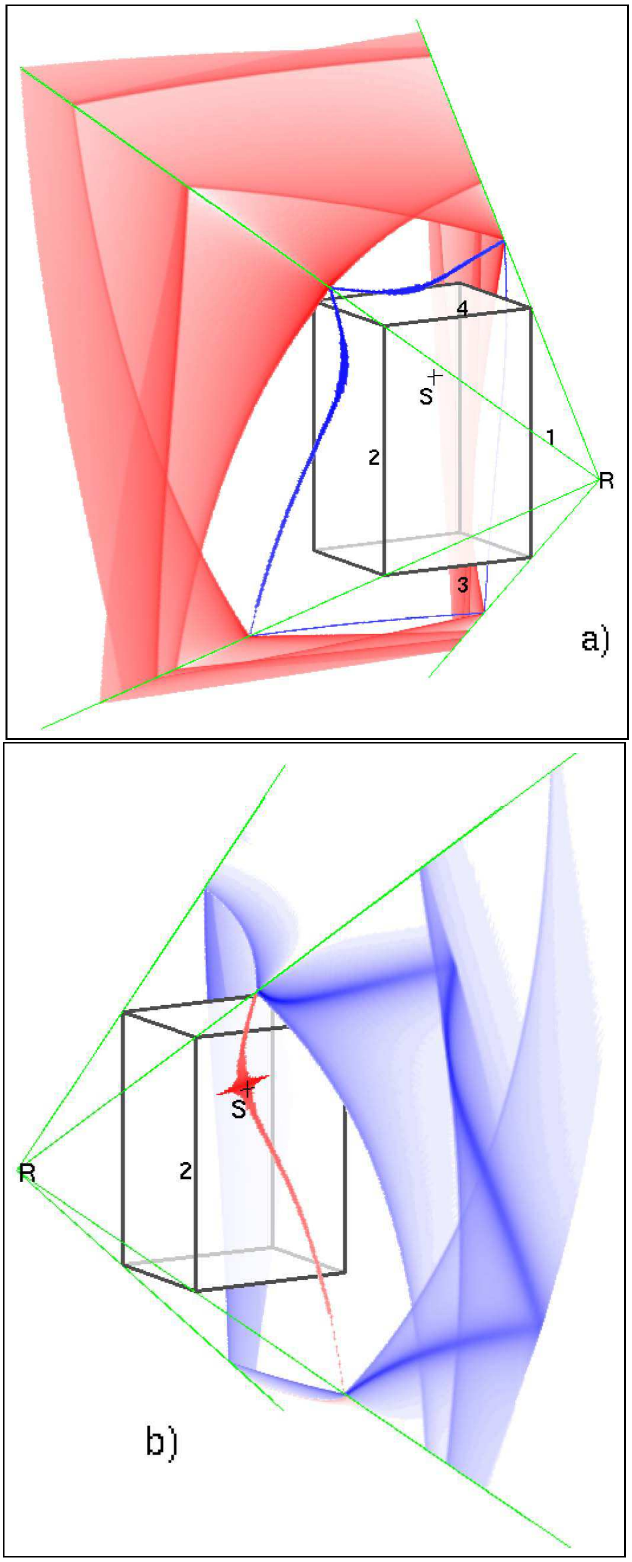

Figure 5: *Illustration of first- and second-order diffraction around a rigid loudspeaker enclosure. a) Receiver in front of loudspeaker. b) Receiver in the* 95° *azimuth direction. The magnitude of second-order diffraction has been amplified by 20 dB.*