Indoor Sound Visualization

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INTRODUCTION

Currently there are few scientific tools that exist today that help with visualizing sound indoors. The tools that do exist are expensive and are used mainly for professional purposes such as speaker setup in concert halls and theaters. More specifically, when preparing point-source based audio today, there is no easy way to visualize reflection, refraction, transmission and absorption that occurs within a given environment. These factors are all heavily dependent on the amplitude, frequency, and direction of the sound waves being produced as well as how they strike the boundaries of a given environment. The boundaries of an environment are made of different materials, which have a direct effect on the sound being produced. The change in material also causes variations in the amplitude throughout the environment at different locations. Different materials reflect, refract, and absorb sound with different properties. In order to show the many effects that are associated with sound indoors, we wanted to develop and present a potential solution to the current problem that exists. Taking inspiration from an excerpt in Gary Davis' and Ralph Jones' book, "Sound Reinforcement Handbook," we decided to develop a tool that would allow for more accurate and scientific indoor sound visualization.

In order to visualize this, we simulated a static environment that contained a point-source audio location. The sound produced from the point-source audio generates invisible data that represents the sound, which humans cannot see. We attempted to visualize this data based on the amplitude and frequency data that is generated by the audio source. In addition to this, we also wanted to visualize different points of the environment where sound is reflected, as the sound waves vary depending on the coefficient of the material of the environment. In addition to this, the distance between the audio source and the boundary also plays a significant role in determining the amplitude of the reflected waves. The sound waves will be shown visually by outward radiating concentric circles that will change depending on when and where they reflect off of the given environment's boundaries. We attempted to keep the physics behind the sound visualization as accurate as possible in order to maintain simple functionality and ease of use for our users, however certain discrepancies were encountered when encoding scientific properties into an externally cognitive interactive information visualization. Further discussion of the specific discrepancies we had to resolve are included later on.

Our indoor sound visualization will hopefully serve as both an educational tool as well as a professional tool in the future that users can use to help professional audio engineering for indoor acoustic environments. As an educational tool, we hope that this visualization software will help users better understand how sound travels and how it behaves within an enclosed space.

RELATED WORK

The Sound Reinforcement Handbook

This book was our group's main inspiration behind creating our interactive data visualization. We focused mainly on the section "Sound Indoors" to gain an critical understanding of omni-directional sound wave's behavior when contained by acoustic boundaries. This section provided us with nearly every function and equation we needed to explain the relationship between our point-source and all of its resulting reflections, in terms of both the resulting amplitude the reflection would have, as well as the distance at which they would occur.

This text also provided us with an initial idea for the visual scope of the visualization, as seen in Figure 1. We knew that it would be far too difficult to accurately represent every individual reflection, so based on the static visualizations in the book, we decided to represent only those that were most critical in understanding the formations of acoustic anomalies within our visualization environment. Additionally, Figure 1 helped us decide which reflections were critical to display, as in only the direct signal and the primary reflected signal (no reflections of reflections).

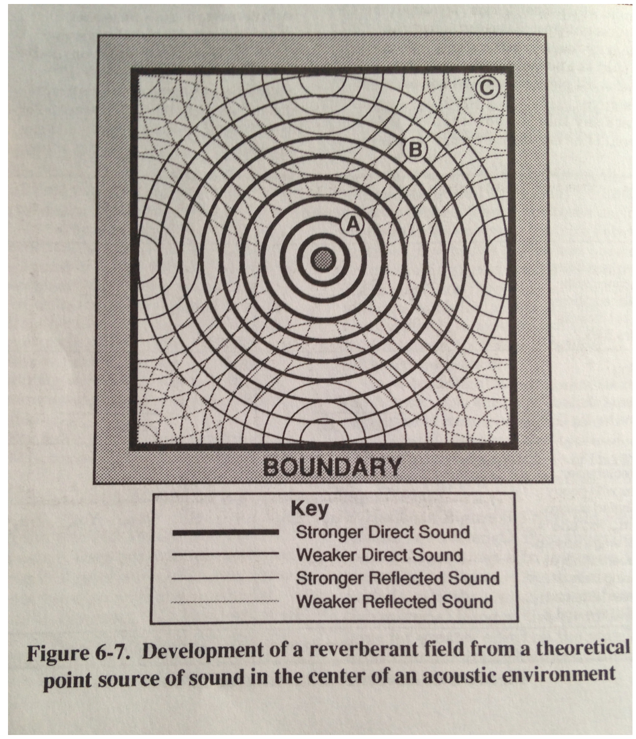


Figure 1. Indoor Sound Visualization Model from "Sound Reinforcement Handbook" (Davis & Jones)

D&B Audiotechnik ArrayCalc

An example of a related piece of modeling software is D&B Audiotechnik's ArrayCalc (as shown in Figure 2). This software statically simulates response from various D&B speakers, notably both point-sources as well as line-sources. Many programs like this exist, and their use is typically stringently enforced by audio system manufacturers in order to avoid damaging their products.

The problems that exist with this type of software is that it does not include analysis of several highly important issues that occur when deploying audio systems indoors. They do not account for reflection most notably, and thus cannot account for room anomalies such as room modes or standing waves that may occur at different amplitudes and frequencies. In addition, the dispersion visualizations provided are static, so when altering data there is no real-time update of how the factors affect the sound produced.

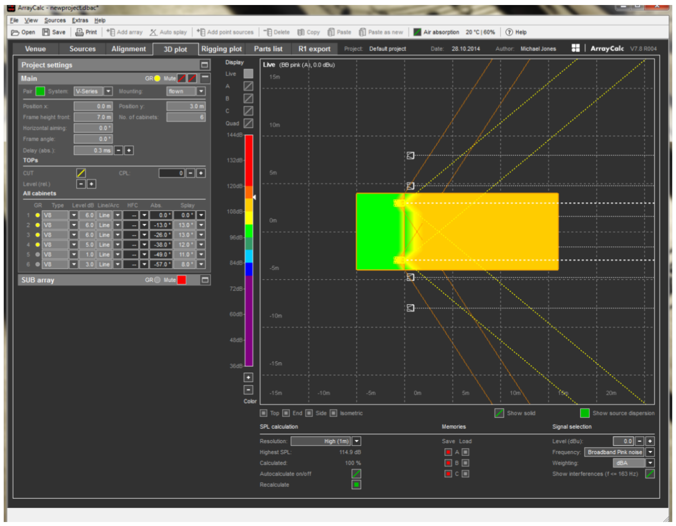
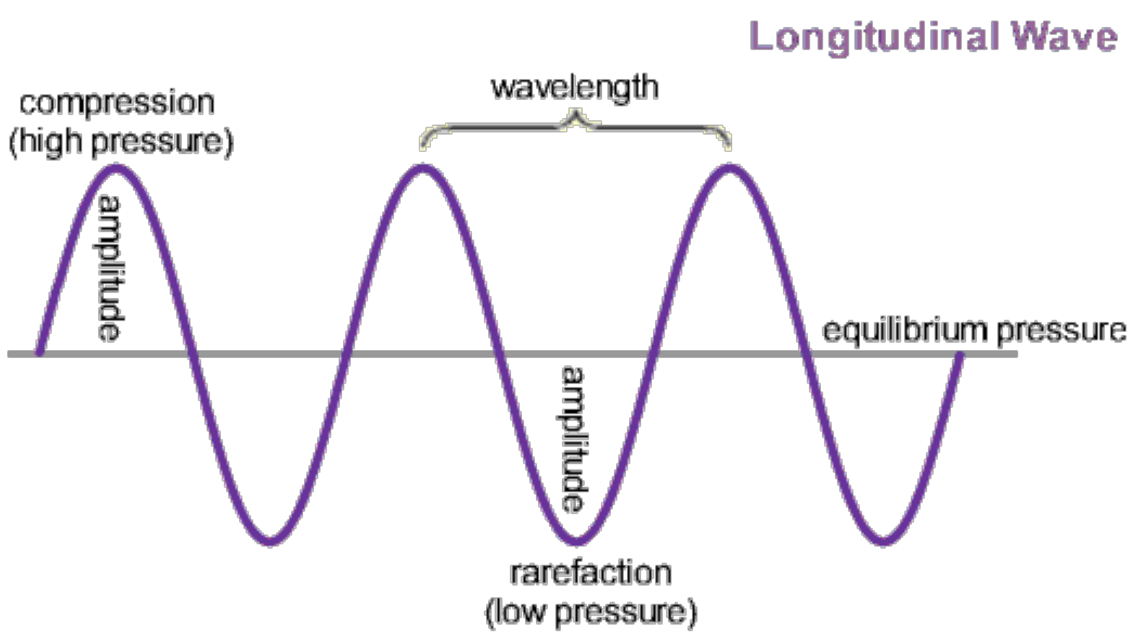


Figure 2. ArrayCalc Array Dispersion Diagram (from D&B Audiotechnik).

Figure 3. Scientific Visualization of a Sound Wave as a Sinusoidal Sine Wave



METHODS

Tools

To build our Indoor Sound Visualization, we used a variety of client-side web development tools including HTML5, CSS, Javascript, jQuery, Bootstrap, and most importantly D3 (Data Driven Documents). Additionally we used the AudioContext javascript object from the Mozilla Developer Network (MDN) to enable an audible representation of the sound that we are visualizing. We used HTML5 as the framework for our application, as it is the universal language of the web, as well as CSS as our stylesheet for similar reasons. Bootstrap was used in conjunction with HTML5 to produce a visually pleasing framework of our software. By utilizing Bootstrap's row-column design, we could effectively display our information by reducing noise, and maintaining an easy-to-follow sequence and organization of ideas. Javascript and jQuery provided the basis for including interactivity in our application, however D3 was the primary contributor for our interaction functionality. Without D3, the fundamental visual aspects of our application would not be possible because of D3's selection abilities, and dynamic properties.

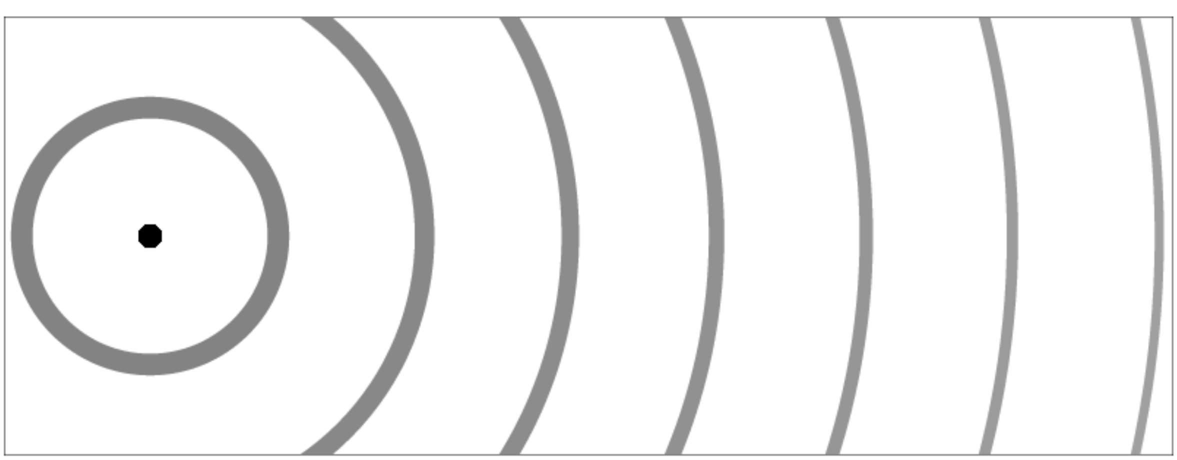
Our Model

Specifically, our application needs to keep track of 3 important variables is visualize: the amplitude and frequency of the sound wave, and the material of the environment that the sound wave's reflections are bounded by. The methods that we used to visualize a sound wave are as scientifically accurate as possible, given our medium of visualization. Because our visualization is merely a model of a sound wave, there are discrepancies in the translation from the scientific model to our visual model. In order to understand the reflective properties of sound given spatial boundaries, we needed to modify the traditional model of of the sine wave. To put this into context, imagine the sine wave in Figure 3 rotated about its x-axis, out of the page 90 degrees, then extended 360 degrees around the audio point-source (black dot) in Figure 4. Our model displays the peaks (compression points) of each sine wave propagating outward in an omni-directional fashion. Thus, frequency corresponds to the distance between the resulting concentric circles, or in this picture, the wavelength. Additionally, the vertical amplitude from Figure 3 is encoded in our model (Figure 4) as the thickness of each concentric circle. Below are the specific techniques and algorithms we used to visualize the amplitude and frequency of the omni-directionally emitted sound wave, as well as the material of the theoretical environment in our visualization.

Amplitude

The amplitude of a sound wave is the distance that the wave travels above the 'zero' vertical position. The amplitude of a sound wave is related to the "loudness" of the sound, which is measured in decibels. Decibels are measured as 10 times the logarithm of the power ratio. The power ratio is the amplitude squared, so the "loudness" of the sound is 10 times the logarithm of the amplitude squared. In our visualization (Figure 4) we have simplified these scientific equations and relationships so that the amplitude is directly related to the "loudness" of the sound, so that our viewers may more easily understand the amplitudes relationship to the "loudness". The amplitude is visually represented as the thickness of the rings, since the vertical position variable is lost in the transposition of the sinusoidal wave model into our visualization. The amplitude decreases relative to the wave's distance from the audio-source, as seen in Figure 4. Since the speed of sound remains constant in any static medium (air in this case), the speed at which the waves travel away from the audio-source never changes. Because of this, the rate at which the amplitude decreases for any given frequency or environmental material is unchanged.

Figure 4. Snapshot of Indoor Sound Visualization with Amplitude '16', Frequency '150', and Material of Environment as 'None'



Frequency

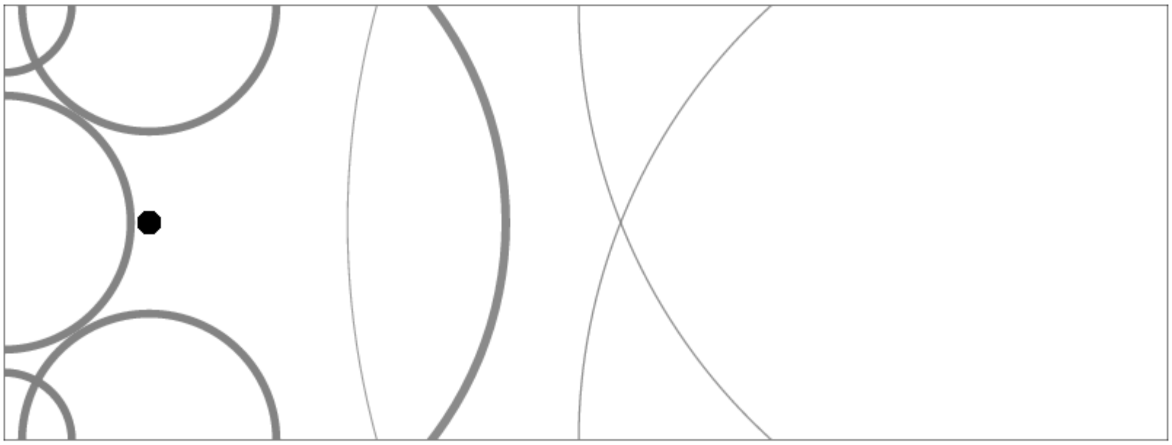
The frequency of a sound wave is measured in hertz, or cycles per second. A cycle in our case refers to one completion of the sound wave traveling from its starting position back again to its starting position. The frequency of the sound wave is directly related to the “pitch” of the sound, so a lower frequency creates a deeper sound, while a higher frequency creates a more high pitched sound. This can be observed through the “Enable Sound” feature, which gives an audible representation of sound wave being visualized. The general perceivable range of human hearing is between 20 and 20000 hertz, but this range is too large to effectively simulate in our model. Because of this we decided to provide a range of 20 to 2000 hertz, which is a more easily noticeable and generally a more pleasant range. When calculating the changes in frequency in our algorithms, what needs to be changed is actually the period of the wave, or 1 divided the frequency. This is because the period is what determines how frequently another compression point of the wave needs to be visualized. In order to make this timed cycle visually noticeable, we had to increase the numerator of this equation to 50,000 to simulate a longer period. This new period was calculated in all functions that drew the audio source or a reflection, and was used as the interval for which to repeat the drawing of the respective audio occurrence.

Material

The material the environment is constructed of defines how much energy is absorbed and how much is reflected. This is determined by the absorption coefficient, where a perfectly absorbent material corresponds to a coefficient of 1, because all sound energy is absorbed. Whereas a perfectly reflective material corresponds to a coefficient of zero, because none of the energy is absorbed. These coefficients were determined by Dr. Wallace Sabine, who has been deemed the father of modern architectural acoustics. For example, acoustic tile has a reflection coefficient of 0.3, because it’s absorption coefficient is 0.7. 1 minus 0.7 is 0.3, which is the percentage of sound that is reflected. “1 minus absorption coefficient” is the equation we used to determine the reflection coefficient for all of our different materials (Sabine). Additionally, as noted by Dr. Sabine in the “Sound Reinforcement Handbook”, different materials have different absorption coefficients depending on the frequency of the sound wave being reflected. Since the vast majority of the frequencies we are simulating are closest to 1000 hz, we decided to use the absorption coefficients associated with this frequency for all materials. There are more complex equations and methods of modeling sound indoors, however for the sake of simplicity in our visualization we decided to stick with our method.

We defined different reflection points along the environment that we thought best modeled the significance of the sound's reflective properties. Similar to setting the interval for repeating simulations of the sound waves, we set ‘time-out’ functions for the reflections of the sound-wave so that they would be simulated synchronously with the original audio source. Generating the proper amplitude upon reflection was arguably the most difficult process in our visualization. The amplitude of the sound wave decreases by a different ratio for each simulated reflection, as seen in Figure 5. The reflections on the left of the environment are similar in

Figure 5. Snapshot of Indoor Sound Visualization with Amplitude '16', Frequency 20, and Material of Environment as 'Plaster'



amplitude since they are similar in position, while the rightmost reflections are much smaller in amplitude since they are much farther away from the audio source. The ratio of energy lost for each reflection was determined by the inverse square law, as stated in the 'Sound Reinforcement Handbook', "Since the direct sound follows the inverse square law, and we assume that the reverberant field's intensity is equal everywhere, it also follows that the ratio of direct-to-reverberant [reflected] sound is in an inverse square relationship" (Davis & Jones). We calculated these values using distance units of approximately one pixel in our actual visualization.

RESULTS

Our visualization is an online tool that enables users to visualize the frequency and amplitude produced by point-source audio within an enclosed environment. The environment that we used is a static rectangular box that currently has a single audio location inside of it. While the material that the enclosed space (theoretical environment) is made of is set to 'None' as default, users have the ability to adjust the material via a drop down menu. Since different materials reflect, refract, and absorb sound waves propagated from the audio source at different frequencies and amplitudes, we decided to visualize this within an enclosed environment in order to educate our users about sound's unique properties. Additionally, the frequency and amplitude produced can be adjusted manually via sliders that are located below the visualization. Lastly, the user has the option to turn the audible sound feature on or off by clicking on a check box.

When a user first visits the webpage they are provided with a description of the visualization as well as the functions of the different sliders and drop down menu. In addition to descriptions on the functionality and what purpose the visualization tool serves, a diagram explaining the properties of a sound wave and what the user is actually viewing in our visualization is also provided. At first, the visualization only displays a single point-source audio inside of a static rectangular box. As the user adjusts the sliders for either frequency or amplitude, visible sound waves begin emanating from the audio source (black dot). Reflections, refractions and absorptions do not take place until the user selects a material for the environment. As stated previously, different materials have different effects on the sound wave emitted. Therefore, we chose to give the user the ability to alter the material in order to visualize these different effects. The dynamic interactivity of the visualization in conjunction with detailed descriptions create a unique user experience for sound visualization.

The current visualization, as it stands, does not allow for good statistical data retrieval as the visualization is simple to use and all tools associated with the visualization have a description explaining both the purpose and how the tool is used. The best method for evaluating our visualization tool's effectiveness in teaching users about sound is through user testing (usability studies). We would conduct usability testing in order to answer questions such as, "Do our users understand how to generate a sound visualization? Are the descriptions clear enough for all user groups? Is our encoding of the scientific model to our visualization accurate for all users?". Users who were tested were able to understand the function of the tool quite easily and felt that the descriptions were a necessary and useful inclusion to the visualization, because it provided further context and information for our tool. Although we have not yet conducted formal user testing on our software, it is our hope that future work on our visualization will include this sort of usability testing. Users also felt that the visualization left them wanting to learn more about sound visualization and see what further functionalities will be added to our tool.

DISCUSSION

Our tool, as is currently stands, serves primarily as an academic tool to help educate users on the effects of indoor sound visualization. We hope that in the near future our tool will allow for more professional use in addition to being purely educational. We plan to add new features and functionality (covered in 'future work' section) which will attract a professional audience by providing critical information for audio testing and help in the engineering of audio systems. Our interest for the development of this visualization tool stemmed from the novelty and originality of the idea of visualizing such an abstract data form (sound).

Building off of our results, our visualization serves as an educational learning tool for beginners who are interested in gaining a better understanding of how sound waves travel, reflect, refract, and are absorbed by different materials in an enclosed and monitored environment. In particular, our tool serves it's intended purpose because it does not require much thought or effort on the user's end because we attempted to have our visualization implement external cognition.

We wanted to develop a visualization tool that optimized the core intentions of a data visualization. From the direct feedback of the audio source when the sliders for frequency or amplitude are adjusted, to the visible effects on the sound wave when the boundary material is adjusted, all components of our visualization create a unique and educational experience for all users. Specifically, since there is no specific data set we are using but rather visualizing the effects of sound waves through slight adjustments to the frequency and amplitude, the tool has the potential to be used for a variety of different purposes.

FUTURE WORK

Once we have confirmed the scientific integrity of the groundwork of our visualization, it will be possible to take this tool in a number of directions. Once this important step is taken care of, we would like to add another layer of dynamic interactivity by allowing the user to alter as many attributes about the environment as physically possible. This would include but not be limited to such elements as the environment's shape, dimensions of the environment, temperature, location of the audio source, type of audio source (including different source input ex. music, multiple frequencies), number of audio sources, and additional boundaries within the environment. A different type of audio source input could include the computer's microphone, so users could speak or sing into the microphone and have the sound waves that they producing become visualized. We would also like to include a tutorial, to walk the user through the function of our visualization step by step.

In the future, we envision this visualization making a transition from an educational tool to an industry tool, providing crucial information for deploying audio systems. This future tool would likely exist as a mobile application, allowing industry professionals to better understand how their environments shape the audio system they deploy. This tool's goal would be to provide external cognition on the level of optimizing currently available systems and enhancing the user's understanding through allowing them to dynamically interact with a data form not traditionally visualized.

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