Optimisation of **Subwoofer Placement** using a **Finite-Difference Time-Domain Acoustic Simulation**

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1. Introduction

- Resonances caused by room boundaries (called "room modes") result in *localized* peaks and lows for specific lower frequencies[1].
- The placement of a subwoofer has significant impact on this effect, and as such, the quality of the sound reproduction.
- To complicate matters, sound can diffract (bend) around objects.
- This complex interactions makes it difficult to find an optimal location in rooms with objects or complex geometry.

2. Optimization Goal

***Locate** an optimal **placement** for a subwoofer for which the **frequency response** has **minimal variation** using an acoustic simulation.*

3. Acoustic Simulation

To simulate sound, the Finite-Difference Time-Domain (FDTD) method[2] is used. Using this method, the acoustic wave equation is approximated as a discrete function in space and time. Each point in space is updated based on its neighbours' and previous values. An OpenCL implementation of the standard leapfrog compact scheme was used in this work[2].

A simulated sound wave is being reflected and diffracted in Figure 1b. With a continuous sinusoid signal, interference can be simulated, as shown in Figure 1c. The response is locally measured as Sound Pressure Level (SPL) in decibels (dB).

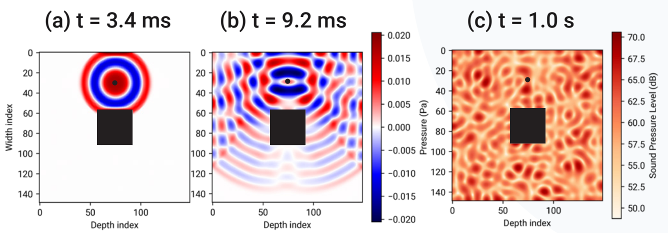

Figure 1: A continous 800 hz sound wave moving through a 4m x 4m x 6m room. In (a) and (b) the effect of reflection and diffraction for the sound pressure is visible. After time, construtive and destructive interference patterns start forming in the Sound Pressure Level, shown in (c).

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4. Method

For the optimization, the first step is to virtually recreate a room. A grid is created that contains information about the geometry, pressure and SPL at each discrete grid cell. All possible subwoofer cell locations are evaluated and their variation in response over a set of frequencies is calculated. The variation is defined as the sum of squared errors of the deviation between frequencies. The process is shown in Figure 2. Reflective surfaces are frequency dependent and thus updated for each frequency.

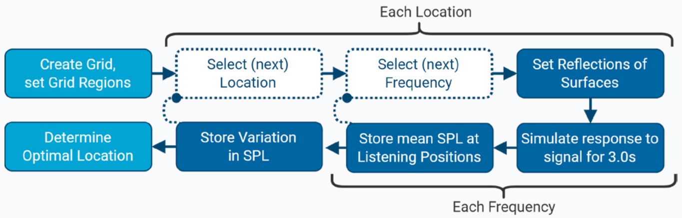

Figure 2: The optimization method. For every location and every frequency of interest the frequency response variation is calculated and an optimal is found.

5. Verification

To validate the simulation, a physical measurement was performed in a room and compared to its virtual counterpart. The results can be viewed in Figure 3. There is a correlation between measured and simulated, but not every room mode causes equal variation in response.

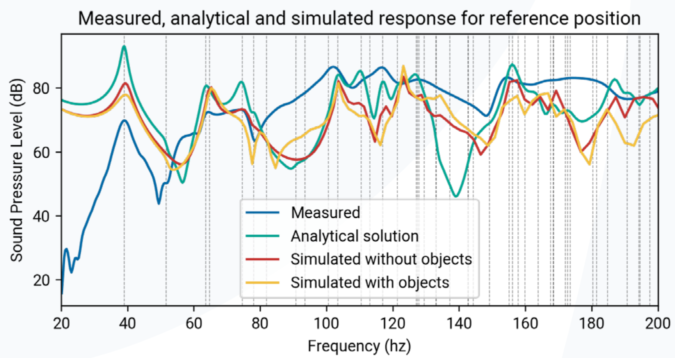

Figure 3: A comparison between the frequency response of a measurement, the simulation (with and without objects) and an analytical model. The subwoofer is rated for 30 - 120 hz.

6. Results

Each possible subwoofer location was evaluated for the virtual room used in the verification. Figure 4 shows the frequency responses of the positions with the most and least variation.

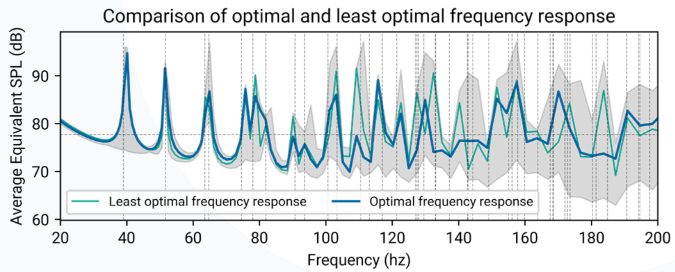

Figure 4: A comparison between the frequency responses with the least and most variation. The maximum and minimum for each frequency are highlighted in the background. The optimal response still contained variations at certain resonant frequencies, but overall had less variation than other locations.

7. Conclusion

- The results show that this method correlates to both a measured frequency response and an analytical model.
- The optimal location predicted with the simulation could not flatten every room mode but had decreased variation for a number of resonant frequencies.
- The method can be useful for rooms that contain large objects or special geometry, for which a trivial solution is inaccurate.

8. Future work

The simulation can be improved to increase accuracy. Future work can investigate if the method can be extended to multiple subwoofers, and/or reduce the number of simulated subwoofer locations.

References

[1] Welti, Todd and Allan Devantier. "Low-Frequency Optimization Using Multiple Subwoofers." Journal of The Audio Engineering Society 54 (2006): 347-364.

[2] K. Kowalczyk and M. van Walstijn, "Room Acoustics Simulation Using 3-D Compact Explicit FDTD Schemes," in IEEE Transactions on Audio, Speech, and Language Processing, vol. 19, no. 1, pp. 34-46, Jan. 2011, doi: 10.1109/TASL.2010.2045179.