Efficient acoustic modelling of large acoustic spaces using finite difference methods

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# INTRODUCTION

* Introduce reason for doing study
  + Improvements in simulation performance help predictions, exploration (rapid prototyping) and design decisions – improved audio quality in the end
  + Large scale simulations are hard to do using wave method
  + If we get the speed up by some clever means (and ideally the memory restrictions down) the methods could be made more accessible for less specialist users i.e. PA and loudspeaker designers, students etc
* Lit Review
  + Central to FDTD is work by Bootledooren[1], SFDTD is work by Doerr [2]
  + This work has been used and expanded upon by many researchers such as Hill
  + Work by those such as the Hornikx [3] and angus [4] have bought PSTD into the acoustic domain
  + Work by Doerr introduced SFDTD to PIC simulation
  + Basic description of technology – time domain acoustic methods are often used for Low frequency acoustic simulation
* Defined marker – regardless of approach it’s important to try and get a reduction in the time taken to do a simulation – MAIN GOAL
* All above was setting the scene > there is this technology and it does this….
* Introduce the problem
  + Much of the literature has expressed how long it takes to do an FDTD simulation, and FEM and BEM can be faster, but isn’t always, and isn’t quite as flexible
  + An explanation of the problem in brief – Hard or impossible to model larger spaces on a normal PC with FDTD, is it worth exploring faster solvers
  + Introduce FDTD
  + Give some explanations of some practices in FDTD that may slow it down
  + Introduce PSTD and SFDTD and explain why this may speed things up
  + Explain the limitations of PSTD
  + Explain the limitations of SFDTD
  + Explain why those limitations are important in more detail
  + Figures backing up the problems
* Explain what this paper is all about – This paper is a cursory glance into a deep problem, that might be helped with some cunning future work
* Split out the content of the paper – the tests, results and such

This paper describes early research into the execution speed performance of time domain wave equation based acoustic modelling. The work was undertaken in Matlab, as part of an MSc project at the University of Derby.

# Experiment

* Introduce the experiment conditions: - WHERE (and why where)
  + Experiment done on a windows 10 PC with an I5 and 16GB Ram because I am poor
  + We Accept this was not ideal – but you gotta piss with the cock you got!
* A little bit more about the method – HOW of the thing measuring
  + Aim: to directly examine the time it took to get to a roughly similar solution
  + We used a series of domain sizes of the same shape and reflectance
  + Measuring points in a grid of so much
  + Centre of grid was in middle of the space
  + Domain size was dictated by how much memory I had access to
* Setup of the methods – HOW of the variable 1 domain setup
  + Three sets of domain setups required for each method, to keep stability and such
  + 1 – FDTD setup – dx dt etc
  + 2 – PSTD setup – dx dt etc
  + 3 – SFDTD setup – dx dt etc
  + WHY the setups? We want a reasonable behaviour, but it will never be true to real life – CAVEATS AND LIMITATIONS ARE IMPORTANT HERE
* Setup of the source and the stimulus – WHY?
  + Single omnidirectional source with tonebursts
  + WHY that source? To find out if there is smear or other nasty behaviour, and stability too – FIGURES OF THIS DATA
  + Specifically, this will happen if there is a minimum of 60cm between subwoofer cabinets or cabinet and wall
  + Sub was operated in 100Hz mode – so passband was 39 – 110 Hz
* Defining the baseline – HOW
  + The behaviour of the subwoofer was measured on its own, to get a baseline of the performance of the speaker in the space
  + Introduction of measuring software – CLIO was used
  + Introduction of stimulus – MLS
  + HOW – mic placement – 1 cm from floor WHY? To avoid the floor reflection
  + Examined at three frequencies – 40Hz 80Hz and 120Hz
* Reviewing the results – WHAT & WHY
  + There are exceptions in that other stuff in the measuring space is stores asymmetrically around the measurement circle – WHY
  + Data shows front-back rejection of between 14dB and 16dB which agreed with the manufacturers data if you ASSUME 5dB increments - WHAT
  + The on-axis frequency response is similar – falls at 40Hz by about 30dB to 20Hz which is what’s published - WHAT
  + The HF boost at 90Hz is probably a room effect - WHY
  + NOTE: NOISEFLOOR OF THE MEASUREMENT IS HIDDEN
  + NOTE: PLOT SCALE
* Small stage configuration – HOW
  + A single piece of deck of such a size was introduced into a configuration – WHAT – FIGURE 6 EXAMPLE OF THE CONFIGURATIONs
  + The purpose of the configuration was to see what a single piece of deck did – WHY
  + Would one piece of deck make no change – QUESTION?
  + Because the deck as small dimensions – WHY TO THE QUESTION
  + This is a first step towards better understanding the issue – WHY DO THIS TEST
* Large stage configuration
  + Before sharing the results, explain the next step
  + The next step was the expand the stage to be more similar to real life events – WHY- FIGURE 7 EXAMPLE OF THE CONFIGURATION
  + In this case it’s a 3\*3 grid or 7.3m by 3.65m – WHAT
  + The stage height was restricted to 0.52m due to available legs – WHAT and WHY
  + Because of the height limitation the sub couldn’t fit under the stage – WHAT
  + So the under-stage configuration was modelled in FDTD – WHAT & WHY
  + To give an approximation of the effect – FURTHER WHY
  + Explain that this stage is still small compared to big events, but is big enough to give a good idea – WHAT

# Results

* SMALL STAGE SECTION
* Reiteration the conditions of the experiment
  + The three subwoofer positions were analysed in terms of the shape of the polar plot – WHAT
  + The figures below show the polar plots and frequency responses for no stage and a single stage are given – WHAT
* Explanation of what the results show
  + It can be seen what the frequency responses in-front and behind with one piece of deck make little to no change In the audience area – WHAT
  + On and under the stage subwoofer positions there is a clear difference in frequency response with the deck in place, with a 15dB increase at 55Hz, and a collapse in the cardioid polar response when measured both on and under the stage – WHAT
  + With the subwoofer just in front of the stage, you get better on axis performance than the other two subwoofer positions
* A look at the results from another point of view
  + Its necessary to compare the frequency responses in more than on axis and off axis – WHAT
  + The 6 +/- 20degree measurement points were ignored because people aren’t normally there – WHY
  + The groups (onstage and audience) were averaged to give an idea of system behaviour in the audience and on the stage – WHAT & WHY
  + The averaged frequency responses with the single deck stage were taken from the no stage ones to give a deviation – WHAT & WHY
  + These responses are given in FIGURE 10 – WHAT FIGURES SHOWING DEVIATION
* Rounding off this part of the analysis of the effect of the small stage
  + This analysis provides ‘conclusive’ evidence that the best place to have a subwoofer around one piece of stage deck is in front of the deck – WHAT
  + This place exceeds or matches the front-to-back rejection ratio of the subwoofer with no deck – WHY
  + The under and on stage placements show reduction in the stage rejection in the subwoofers passband – WHAT
* LARGE STAGE SECTION
* Introduce the large stage results analysis
  + An identical analysis to the small stage was done with the large stage – WHAT reiteration
  + The polar plots and frequency responses are given in the below FIGURES
  + Under stage placement wasn’t possible so the data is modelled – WHAT reiteration
* Compare the results between large and small stage
  + There are some similar and dissimilar trends – WHAT
  + The under stage location appears to be the worst choice in both cases, even though the large stage data was modelled – WHY/WHAT
  + So more investigation is needed – WHAT
  + Between 60 and 90Hz, there is less front-back rejection for the in-front of stage position than with no stage – WHAT
* Explanation of why a big stage makes a difference, and the effect of the rear wall on the experiment – BIG EXPLANATION OF WHY SOME UNEXPECTED VARIANCE
  + A possible explanation is the big stage is acoustically larger in the subwoofer passband, so most frequencies interact with the stage - WHAT
  + A wall was just behind the stage, so a strong reflection may have interacted with the measurements – WHY
  + The propagation distance of the reflection was 9.7 meters for the first driver of the subwoofer, a wavelength relative to 17.68Hz - WHAT
  + Odd integer multiples of this arrive at the sub 180degrees out of phase with the direct output of the sub, causing cancellation in front of the drive unit – WHY
  + Key frequencies of this odd order multiples are 53Hz and 89Hz – WHAT
  + The propagation distance of the reflection for the second driver is 8.7 meters, equating to integer multiples of 59 and 99Hz – WHAT
  + The significance of this loss of stage rejection requires further work – WHAT
* The average front-back rejection ratio analysis
  + Finally
  + Mean front-back SPL rejection over two frequency ranges (38 – 110Hz) and (20-300Hz) – WHAT
  + Wider range to account for stage and room resonances –WHY
  + Is given in table 1 & 2 – WHAT
  + The data in those tables give a clear and concise summary – WHAT
  + Placing a cardioid subwoofer on top or under a stage, regardless of stage size, will reduce the front-back rejection ratio a lot! – WHAT
  + Placing the subwoofer in front of the stage will allow the rejection to be maintained – THE BIG OUTCOME OF THE STUDY – THE WHAT

# CONCLUSION & Further Work

* Review of the results and final outcome
  + The results in the paper aid further understanding of the problem – the effect of the stage on the polar response – WHAT
  + If a sub is under or on top, the speaker won’t have the same great directivity – WHAT
  + The result is high SPLS on stage which is no good – WHAT
  + Placing the sub in front of the stage is the best for maintaining the polar response – WHAT
  + The results here and the results from earlier work show that its best to place the sub in front of stage – WHAT BIG WHAT
* Caveats
  + This analysis is meaningless if the subwoofers are flown above the stage – Counter point
  + If you do this, do beam steering so that there is less noise on the stage
* Further work
  + While this work shows some good evidence, more work needs to be done to fully know what is going on – WHAT
  + These recommendations for further work – WHAT
    - Repeat experiment in anechoic space with full stage
    - Repeat experiment in a large scale live event
    - Examine how multi-unit cardioid subwoofer arrays interact with each-other in different shape arrays with different stage positions
    - Investigate effects the stage has on transient response
* Fourth paragraph
  + Although more work needed to understand, it is clear that you should think about where to place ground based subs at events, especially when directivity is important. – WHAT WIDER
  + Most commercially available software omits any stage effects, so it’s essential to know what the stage does to sub cardioid performance, so not to mess up and to get best response shape – WHAT

## Speech Analysis Research

### Development

# References

[1] J. De Poorter and D. Botteldooren, “Acoustical finite-difference time-domain simulations of subwavelength geometries,” *J. Acoust. Soc. Am.*, vol. 104, no. 3, pp. 1171–1177, 1998.

[2] C. Doerr, “SPARSE FINITE-DIFFERENCE TIME DOMAIN SIMULATION,” US 2014/0365188 A1, 2014.

[3] M. Hornikx, T. Krijnen, and L. Van Harten, “OpenPSTD: The open source pseudospectral time-domain method for acoustic propagation,” *Comput. Phys. Commun.*, vol. 203, pp. 298–308, 2016.

[4] J. A. S. Angus and A. Caunce, “A GPGPU Approach to Improved Acoustic Finite Difference Time Domain Calculations,” *128th Audio Eng. Soc. Conv.*, 2010.