Acronyms

VAE Virtual Acoustic Environment . . . 5
VSS Virtual Singing Studio . . . 3
RIR Room Impulse Response . . . 5
ISM Image Source Method . . . 7
TO Transition Order . . . 9

first: Click here

Second: Click here

Contents

Introduction

No prior understanding of room acoustics is required to appreciate the difference in sound experienced when talking, singing or playing an instrument in rooms of different size and interior. For those who listen even more closely, the effect of standing in different positions of a room can also be appreciated, such as the deep booming sound of standing in a corner or the fluttering echo heard when clapping in the centre of two symmetrical walls. However, the benefits of the hard work that has gone into studying room acoustics and sound propagation are apparent across multiple platforms, from understanding how to acoustically treat a room to make it sound the way we want, to creating tools and defining methods that allow us to recreate or synthesis a rooms acoustics, leading to the ability to development realistic soundscapes to bring virtual worlds to life, such as in video games and films.

The ability to do such things has been utilised in other areas of research, such as studying how musicians perform differently when playing in rooms with different room acoustics [1]. This has been done at the University of York, where the benefit of being able to simulate the acoustics of multiple rooms within moments has been used to effectively transport musicians and researchers to different venues without having to travel anywhere. The system used to do this is the Virtual Singing Studio (VSS), upon which this project is based. In addition to allowing a user to simply hear themselves in different venues, this project aims to allow the user to also move themselves around that venue, allowing them to experiment with performing in different positions.

The rest of this document will be structured as follows:

Background
An overview of all the material that form the basis of this project, including an overview of the software used to achieve the end result. Previous work is discussed, leading to a full description of the project including the motivation behind it. Finally, the project aims and objectives are stated, including how the system was to be produced and tested to access plausibility, providing a set a metrics that are used to access the success of the project.

Implementation
This section presents the practical work that was carried out throughout the project, describing the decisions made, issues encountered and how they were overcome.

User Testing
The procedure that was carried out to test the implemented system is described and the results are presented and discussed, followed by a conclusion, highlighting potential reasons for the

obtained results.

Project Management
A brief overview of how the project was planned and time managed.

Conclusion
The project as a whole is summarised and measured against the initial metrics set, evaluating the overall success of the project. The issues raised throughout previous sections are reviewed and potential solutions are discussed. Further improvements to the system are suggested, including some of the work that was initially intended to be carried out.

Background

The following section covers material that forms the basis of the system produced as a result of this project.

3.1 - Virtual Acoustic Environments

Virtual acoustics has been previously described [2] as follows:

> *"Virtual acoustics is a general term for the modelling of acoustical phenomena and systems with the aid of a computer"*

By this definition, a Virtual Acoustic Environment (VAE) can be thought of as an environment (such as a room) for which the acoustical phenomena have been either recreated or synthesised. To produce a VAE, prior knowledge regarding the room which is to be acoustically recreated must be known; how do all audible frequencies propagate around the room for a set sound source location and receiver location?

This information can be gathered by taking a Room Impulse Response (RIR) and used to recreate the acoustics of a room for the set sound source and receiver location.

3.2 - Room Impulse Responses

In order to reproduce the acoustical phenomena of a room, an RIR must be obtained. This is done by exciting all audible frequencies within the room by using a sound source such as a loudspeaker, and recording the result using a receiver microphone.

There are a number of techniques used for exciting all audible frequencies. These include an **impulse** (such as a starter pistol) or an **exponentially swept sine** for which a sine wave is exponentially increased in frequency over a fixed period of time. The difference between these techniques is that an impulse emits all of the audible frequencies into the room at the same time, where as the sine sweep does it gradually. As the idea is to obtain an **impulse**, using the impulse technique is much more simple as no post processing is required. Using an exponentially swept sine requires post processing in order to time align all of the frequency dependent room reflections through the use of a deconvolution algorithm and thus producing an impulse response, making this method a little less simple. However, this method produces a greater signal to noise ratio thus is the desired method [3]. Once the impulse is obtained, it can be convolved with an audio signal, making that audio signal sound as though it is being produced within the room that the RIR was taken from. Convolution simply takes an input signal and multiplies each of the discrete samples with the impulse response, thus simulation the effect the room would have on each of these samples if they were actually emitted in the room itself [4].

3.3 - Ambisonics

Though using an omni-directional microphone to record an RIR is a set standard [5], it is also possible to use techniques such as Ambisonics to record RIR's that can be used to reproduce a soundfield in three dimensions.

Ambisonics is a technique used to encode and decode three dimensional spatial audio information using just four audio channels. A three dimensional sound field can be recorded using a microphone known as a Soundfield microphone shown on the left in figure 1. These microphones contain four coincident capsules, one of which is an omni-directional capsule (W) and the rest of which are figure of 8 capsules used to record sound in the X (front and back), Y (left and right) and Z (up and down) direction illustrated on the right in figure 1. In theory, the aim is to record the sound field at a single point, however this will never be possible given that the microphones take up physical space. Therefore, the sound captured by the microphones are first recorded into A-format (raw unedited signals) and then converted to B-format which is the same signal with an applied inter-capsule time correction to compensate for the physical separation of the microphones [6] and the fact that they are not absolutely coincident [7]. Once the sound field has been captured, a system specific decoder can be used to replay the captured signal over an arbitrary number of loudspeakers.

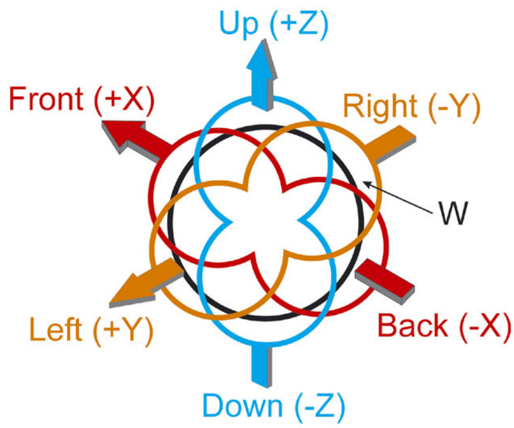


Figure 1: **Left**: Picture of a Soundfield microphone with coincident capsules exposed. **Right**: Soundfield microphone polar pattern. Images sourced from [8] (background removed from left image)

3.4 - Software Overview

3.4.1) ODEON: Simulating Room Acoustics

Methods for physically measuring RIR's within rooms has been discussed, however there is also a way to synthesis RIR's by mathematical modelling the way in which sound interacts with a room. The two ways of doing this are described as **Wave-based Methods** and **Geometrical Acoustic Methods**.

Note: The next paragraph on wave-based methods is adapted from the initially submitted literature review and is not required for the understanding of this project. However, it is provided here as the initial project plan included the use of such methods and is therefore mention later in this section

Wave-based methods are based on solving the wave equation, producing a solution that is physically correct and can be used to accurately model how a sound would propagate from a source in a room and reflect [9]. However, accurately calculating the way in which a wave moves through and interacts with a room is computationally expensive making them impractical for real time simulations.

Instead, it is possible synthesis RIR's by using room acoustic simulation software such as Odeon [10] that utilises the much quicker geometrical methods. Odeon was designed to provide reliable predictions of room acoustics by using a hybrid of two geometric acoustic modelling methods: **ray-tracing** and the **Image Source Method (ISM)** to synthesis RIR's. These methods model how sound would propagate and interact with a room as though it were a straight line (ray). This inherently neglects wave phenomena such as phase and diffraction, properties that are negligible at high frequencies, however they are fundamental in describing low frequency wave behaviour [9]. Therefore geometrical methods are not accurate at modelling sound propagation for low frequency waves, however they provide a good approximation for most applications.

A description of both of the geometrical methods are described below, leading to a description of the hybrid method used in Odeon.

3.4.1.1 Ray-Tracing

The ray-tracing method imitates a sound source by emitting a large number of particles in various directions from a single point [11]. These particles are then traced around the room, losing energy each time the particle encounters a surface by a factor of $1 - \alpha$, where α is the absorption coefficient assigned to that surface, illustrated in figure 2. The angle at which the particle is then reflected is determined by the scattering coefficient assigned to the surface of contact, ranging from a specular reflection to a completely random reflection [12] (described in section 3.4.1.4 Scattering). For a specific receiver position, an area around said point is defined in which rays are collected and used to calculate the results.

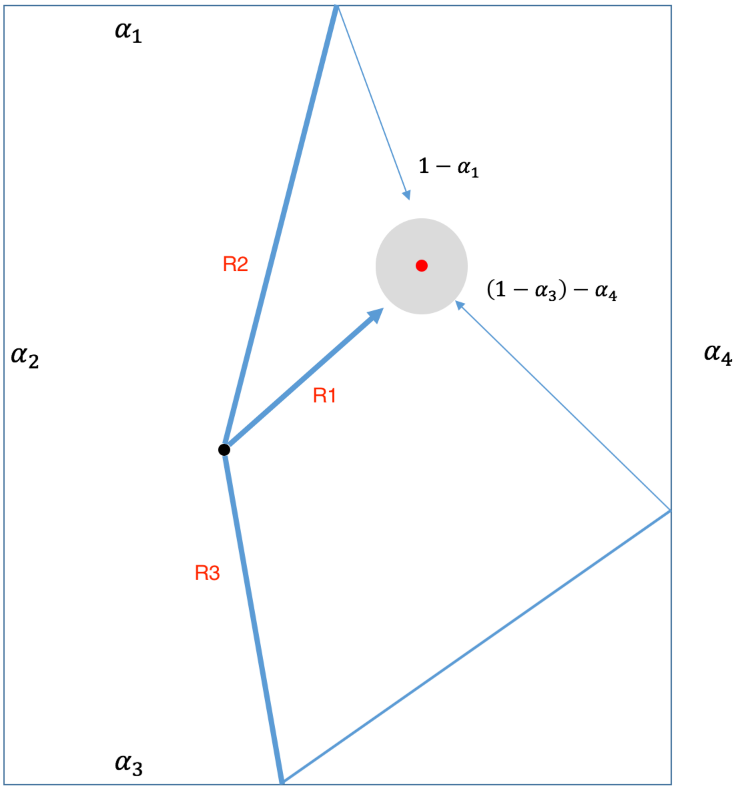


Figure 2: Illustration of the ray-tracing method (by the author) showing a sound source (black) emitting three rays (R1, R2 and R3) and shows how each ray is attenuated by a factor of $(1 - \alpha$ each time it is reflected from a wall. The red dot represents the receiver positions and the outlining gray circle represents the area in which rays need to pass through to be used in the RIR calculation.

Ray-tracing does not provide a completely accurate result as it is a risk that some rays may not pass close enough to the receiver to contribute to the final result. The outcome of the ray-tracing method is a statistical result rather than a complete one.

3.4.1.2 Image Source Method

The ISM can be used to find all possible specular reflections paths from the sound source to the receiver position. This is done by representing each specular reflection (a reflection with angle equal to the angle of incidence) from a surface as a secondary source known as an "image source" [11], illustrated in figure 3. Once these image sources have been created, a visibility test is run which checks to see which image sources are in sight of the receiver thus calculating which image sources should be used in the final calculation of the RIR. If the receiver is then moved, the images sources to not need to be recalculated, only the visibility check needs to be run again. It is due to this that the ISM is much more accurate than ray- tracing which relies on random reflections to calculate an RIR. However, as each new image source emits a number of rays of its own, there is a potential for it to produce a number of image sources. Therefore, with each new image source there is an exponential growth in the total number of image sources, making this method much more computationally expensive than ray-tracing. This problem can be avoided by setting a *reflection order* which determines how many times a ray can reflect around a room before calculations are stopped, thus preventing the creation of more image sources. This however will cause the prediction of the rooms acoustics to be incomplete. This obviously then makes the ISM less accurate with a smaller reflection order.

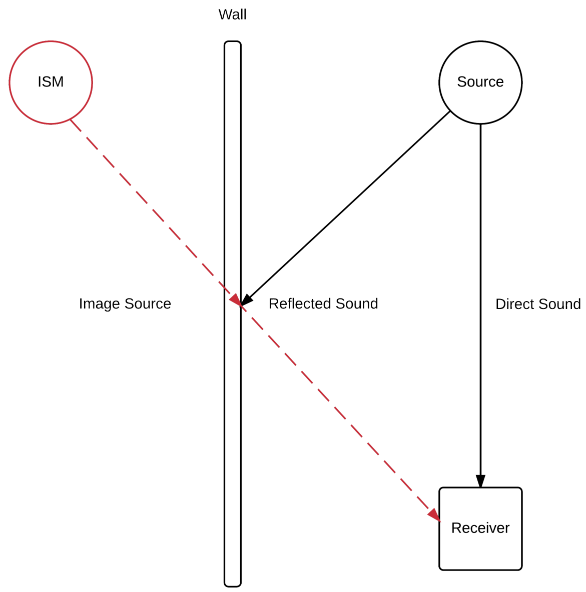


Figure 3: Illustration of the image source method (by the author) showing how the reflection from the sound source to the receiver is modelled by a secondary sound source.

3.4.1.3 Hybrid Method

Ideally, the ISM would be used to calculate all sound rays due to its accurate results, however due to the computational limitations, Odeon uses a hybrid method to provide a reasonable compromise between calculation time and accuracy.

The hybrid method first uses the ISM to calculate a number of image sources up until a specified reflection order determined by a Transition Order (TO). For example, if the TO = 2, the image source method will allow a ray to reflect twice which will produce a number of image sources at which point it will then switch to using the ray tracing method to calculate a statistical model of how the rest of the rays might interact with the room. This gives the user the choice between computation time and accuracy.

3.4.1.4 Scattering

Unless a surface is infinitely smooth (which almost all surfaces are not), when sound comes into contact with that surface it is scattered at a angle that deviates for that at which it hit the wall. Odeon takes this phenomena into account by using 'Vector Based Scattering' [12]. This is done by adding the specular vector to a randomly reflecting vector that has been scaled by a value of 1-s, where s is the scattering coefficient applied to a surface (ranging from 0 - 1). This essentially calculates how much a specular reflection should deviate based on how 'rough' a surface is, where the rougher the surface, the higher the scattering coefficient. Figure 4 shows an annotated image taken from the Odeon manual illustrating this concept.

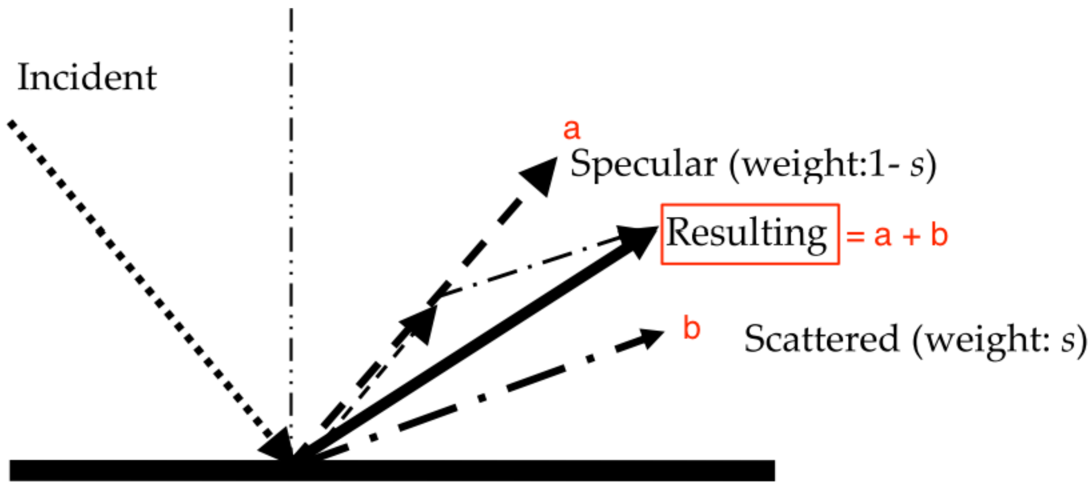


Figure 4: Annotated image from the Odeon manual [12] showing how scattered reflections are calculated, where a = the specular reflection, b = randomly scattered vector.

3.4.1.5 Room Modelling

In order to predict the acoustics of a space, Odeon requires a geometry file in the form of a .par file. This file contains information regarding the room dimensions, object dimensions and positions. This can be produced within Odeon itself by using the built in 'Extrusion Modeller' which allows a user to use a script like language to describe the rooms geometry. It is also possible to use 3rd party applications such as Google SketchUp [13], a software which is described in section 3.4.2 Google SketchUp.

3.4.1.6 Material Selection

Selecting the appropriate absorption coefficients of the surfaces within a VAE is crucial to determining how sound will attenuate as it reflects around the room (as described in 3.4.1.1 Ray-Tracing), thus the accuracy of the generated RIR. Odeon provides a material list with common materials with pre-determined absorption coefficients that can be assigned to the surfaces of a model read from a geometry file. This material list can be extended by creating new materials and assigning absorption coefficients to the appropriate frequency bands.

3.4.2) Google SketchUp

Google SketchUp [13] is an easy to use 3-D modelling software that can be used to produce room models. Unlike Odeon extrusion modeller, it allows the user the draw surfaces with a mouse, easily duplicate structures and provides simple measuring tools and markers to enable accurate modelling. Plug-ins such as SU2Odeon ("SketchUp to Odeon") [14] enables the user to convert the model into a .par file for Odeon to use as a geometry file.

3.4.3) Max/MSP

Max/MSP (Max) is a visual programming language that essentially provides pre-written blocks of code in the form of objects, providing the ability to chain them together in order to route and manipulate audio signals [15]. This allows user to quickly and easily produce audio applications (called patches) without having to deal with the complex side of audio programming. This is beneficial for students and researchers as it allows them to concentrate of the results rather than the application programming itself. Additionally, third-party plug-ins can be incorporated into a Max patch as libraries would in any other programming language. One third-party application utilised in this project is Spat. Developed at the research institute IRCAM [16], Spat is designed for real-time spatialisation of sound signals in Max without having to touch any code. It provides an simple way to convolve B-format audio signals with impulse responses as well as decode the B-format signals for any given number of speakers in any arrangement by simply providing the number of speakers and angles at which they are placed.

3.5 - Project Description

This section starts by explaining what the VSS is and how this project will build upon it. The motivation for doing so is covered and the project objectives and metrics are stated.

3.5.1) The Virtual Singing Studio

The VSS is a loudspeaker based room acoustics simulator used as a tool for analysing the correlation between room acoustic characteristics and vocal performance parameters as part of Dr Jude Beretons PhD Thesis [1]. It is comprised of a head-mounted microphone used to capture a real-time audio input from a singer, a software patch written in Max/MSP that convolves the audio signal with a number of Ambisonic B-Format RIR's using Spat and finally a spherical array of 16 loudspeakers for which the convolved audio signal is decoded and fed to. In addition, a head-tracking device (an Oculus Rift [17]) is also used to track which direction the user is facing in the virtual space. A flow diagram of the system can is shown in figure 5.

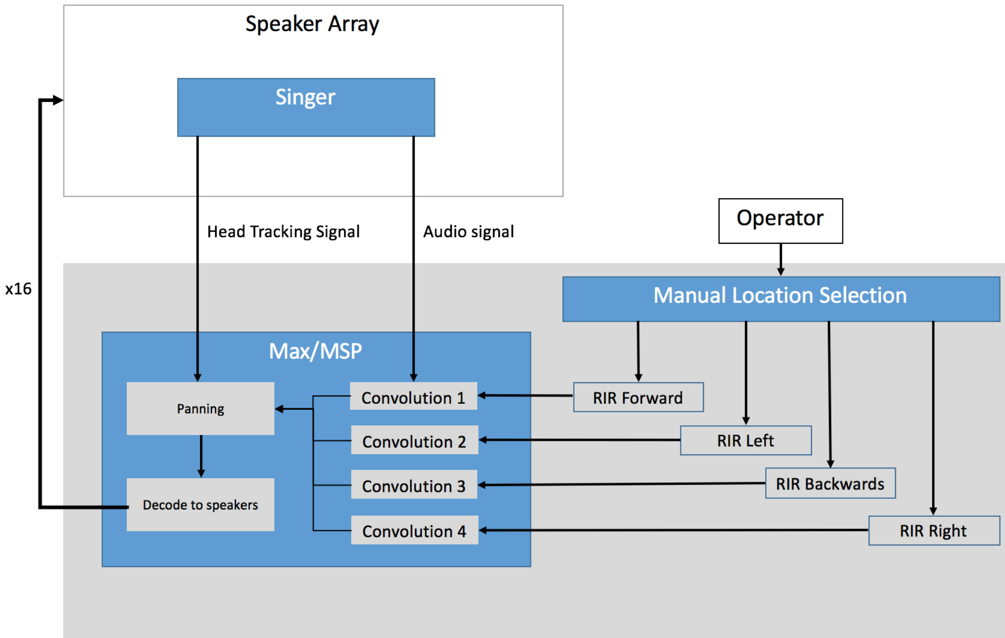


Figure 5: Flow diagram of the VSS showing how the audio signal and head tracking signal form the performer are used in Max before the convolved audio signal is sent back out to the speaker array.

The VAE used in the VSS was initially the National Centre for Early Music, a space in York frequently used for musical performance. Using a Soundfield microphone, Ambisonic B-Format RIR's in each direction (front, left, back, right) were captured in 4 locations. The four directional RIR's are used to approximate the room acoustic phenomena that would occur if the user were projecting in that direction. This is done by using the data from the head-tracking device to amplitude pan the convolved signals before sending them to the spherical speaker array.

3.5.2) Project Aim and Motivation

The VSS addressed a problem faced when trying to research how musicians preform in different acoustic environments: having to travel to each performance space with musicians and researchers. This also indirectly provides a solution for performers wanting to rehearse in spaces that are often inaccessible and would otherwise be expensive to book and travel to. By obtaining an RIR of the desired location, the only time travelling will be necessary is to initially obtain said RIR. However, one limitation of using the VSS is the restriction of position. If a performer wanted to try and sing at another point in the room, an RIR would have to be taken in that position too. This could be done initially, taking a range of RIR's in a number of positions, however it cannot be guaranteed that all positions desirable to the performer will be available. Therefore, this project aims to implement a system that will allow the user of the VSS to feel as though they can move around a VAE freely.

Previous projects have addressed mobility within VAE's before, such as [18]. The paper initially looks at two methods for providing mobility:

1. **Direct room impulse response rendering**: By producing a large grid of RIR's within the desired space, it is possible to allow a user to select a position in the room by interpolation between the two nearest neighbouring RIR's. This method does not provide truly accurate room acoustics for the selected location and also suffers from the fact that a large number of RIR's are required, thus the requirement for a large amount of storage space.
2. **Parametric room impulse response rendering**: By actually synthesising RIR's in real time for the given position of the user in the VAE, it is possible to provide an accurate RIR for the given location. This method avoids the need for a large amount of storage space and a system to retrieve the correct files.

The author stated:

> *"Although a static setting would be technically much simpler, it has only limited applicability"*

For this reason, the authors of said paper used the parametric RIR rendering method, thus no information regarding the process of implementing the system using the direct RIR method was obtained, nor the plausibility of such a system.

It can be said that although parametric room impulse response rendering might be limited in its applicability, for the aims of the project described in this document, it provides a solution that is simple enough to implement within the time given and will allow for the desired functionality. It will also be explained later in this document (**?? ??**) that post-processing of the RIR's are required which would not be possible using the dynamic rendering method. Therefore, as the intention was to build upon the existing VSS system which requires pre-recorded (and post-processed) RIR's and that storage space is no longer a problem due to cheap hard disc drive storage, it was decided that the direct room impulse response rendering method was to be used. In addition to implementing the desired functionality, the following additional information were to be investigated:

The process: Given the apparent simplicity compared to producing a dynamic rendering system, the process of obtaining the RIR's was to be accessed.

Number of RIR's: As one of the points mentioned was the space required to store the RIR grid(s), the number of RIR's required to convince the user that they are moving freely around the virtual space was to be investigated.

System authenticity: Previous test in the VSS have required 'plausibility' test, where the user must evaluate the VAE produced by the VSS without reference to the real venue. This is usually because testing a virtual environment against a real one (authenticity tests) requires travel which can be expensive and difficult. Therefore, by running test based on 'plausibility' a sense of how convincing the virtual room is can be obtained. In the case of other virtual reality systems where the virtual environment does not exist in the real world, only these types of test can be run. Though plausibility test are acceptable, an authenticity test gives more objective results by comparing the simulated VAE to the real thing. Therefore impulse responses of the same room used to designed the VAE were to be taken.

In order for the user to move themselves around the VAE, the Max patch that the VSS was built on had to be extended in the following ways:

1. The production of a user interface that can be used remotely from within the spherical speaker array.

2. The extension of the Max patch that could accommodate the user interface and load the appropriate RIR files required to place the user in the desired location within the VAE.

Figure 6 shows an adapted flow diagram from figure 5 with the added user interface and automatic file searching functionality.

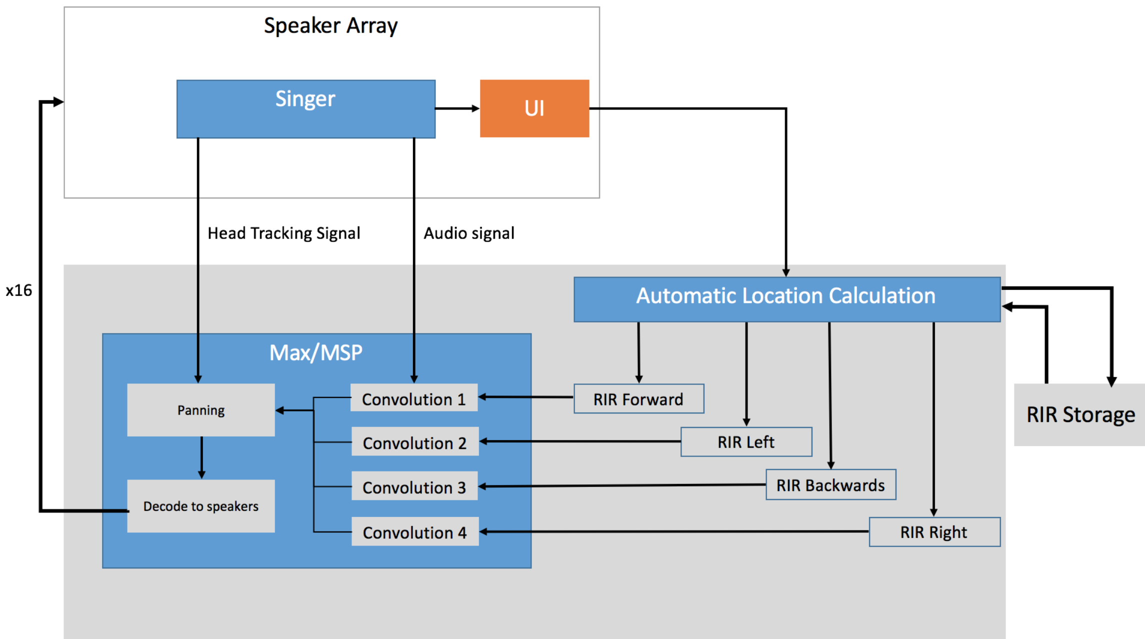


Figure 6: Flow diagram of the way in which the desired extended version VSS works

3.5.3) Project Objectives

Given the project aims and the background provided, the following is a list of objectives that were set in order to complete this project:

1. Find an appropriate room to be modelled as a VAE
2. Digitally model the room using either Odeons extrusion modelling or 3rd part application
3. Import room model into Odeon to finish material selection and RIR settings
4. Produce a grid of RIR's that can be used to interpolate between to simulate user positions
5. Record real RIR's in locations that can be compared to synthetic RIR's
6. Extend upon existing software patch to accommodate new functionality
7. Preform user tests:
   - Test #1: Does the perception of distance change when using real or synthetic RIR's?
   - Test #2: How far does the user have to move in the given VAE before they notice they have moved
   - Test #3: How many RIR's are required for interpolation for the user to feel they are moving around the space freely

In order to test the perceptual differences when using synthetic RIRs (Test #1), real RIRs of the same space had to be taken.

3.5.4) Project Overview

The following outlines the steps that were required to produce a system that allowed a user to feel as though they are freely moving around a VAE and the tasks necessary to investigate the plausibility of said system, thus completing the project aims and objectives set

3.5.5) Room Choice

The following room features were kept in mind when searching for a room to use as part of this project:

Size:	Large enough to be used as a singing space
Simplicity:	Simple enough architecture to be able to model with the time available
Accessibility:	The room had to be easily accessible to take multiple measurements to make blue prints and take RIR measurements

The room chosen was Hendrix Hall, a large lecture theatre on the University of York campus. The room contains retractable seating leaving the large space in the centre open and unobstructed.

The room is architecturally simple being almost perfectly rectangular with the occasional wall indent. With it being located on the universities campus it can be booked for any time of the week meaning it can be accessed when necessary and for free.

3.5.6) User Test Planning

In order to perform the final user tests (test #1 and test #2), minimum distance between RIR's had to be decided.

Appendices

APPENDIX A

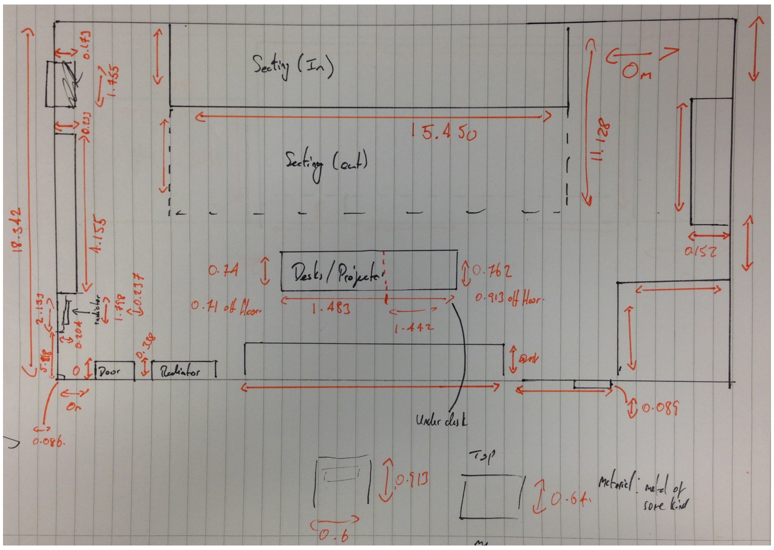


Figure 7: Annotated blueprint of Hendrix Hall from a birds-eye view

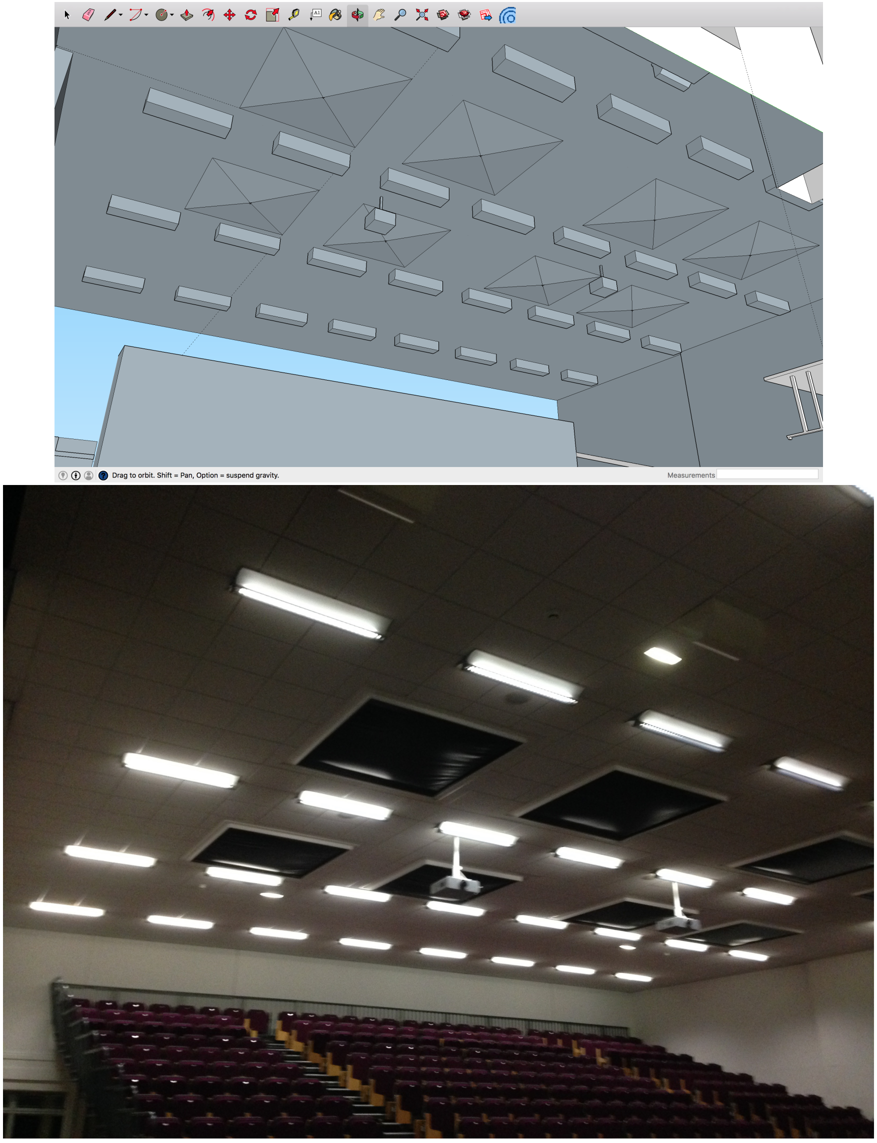


Figure 8: Real Vs SKU Roof

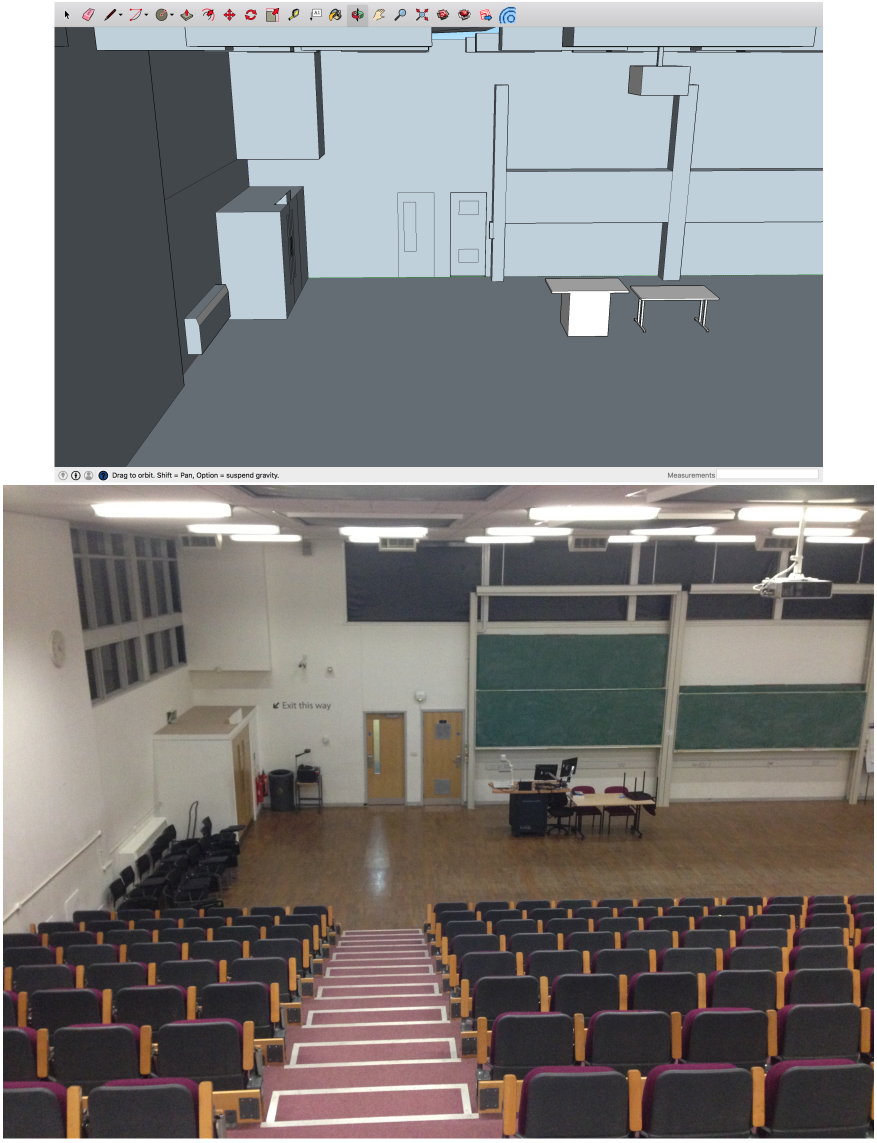


Figure 9: Real Vs SKU Seating Area

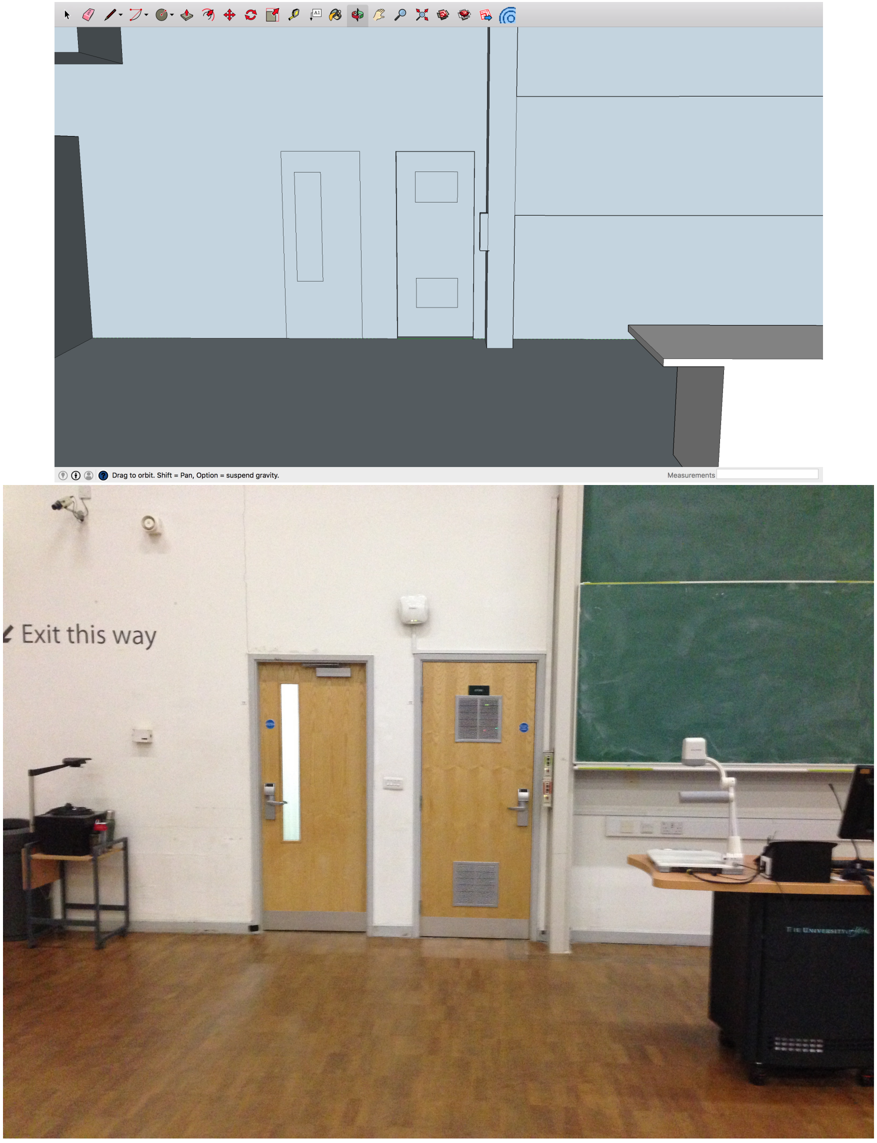


Figure 10: Real Vs SKU Door

Appendix B

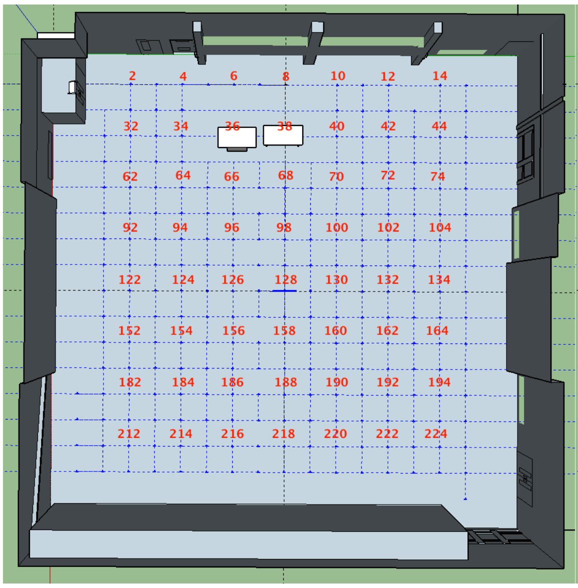


Figure 11: RIR grid with 2m separation

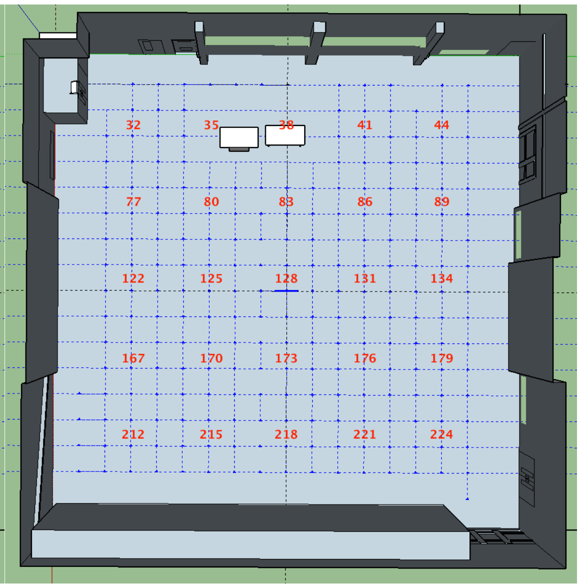


Figure 12: RIR grid with 3m separation

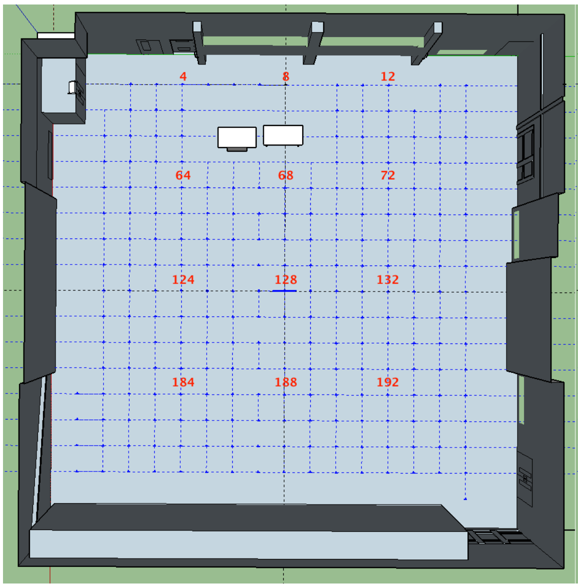


Figure 13: RIR grid with 4m separation

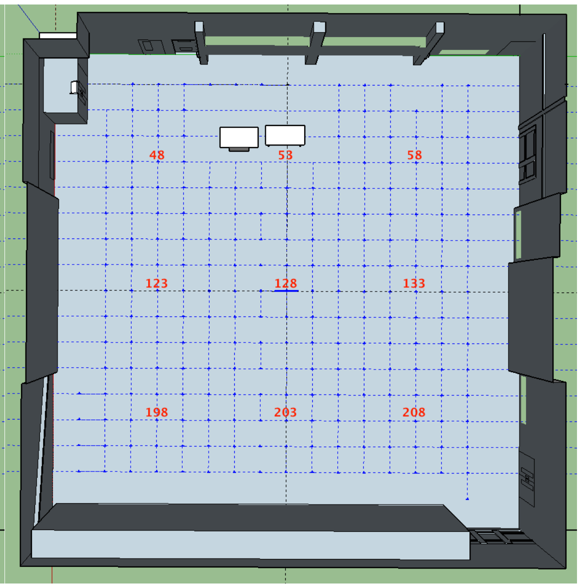


Figure 14: RIR grid with 5m separation

APPENDIX C

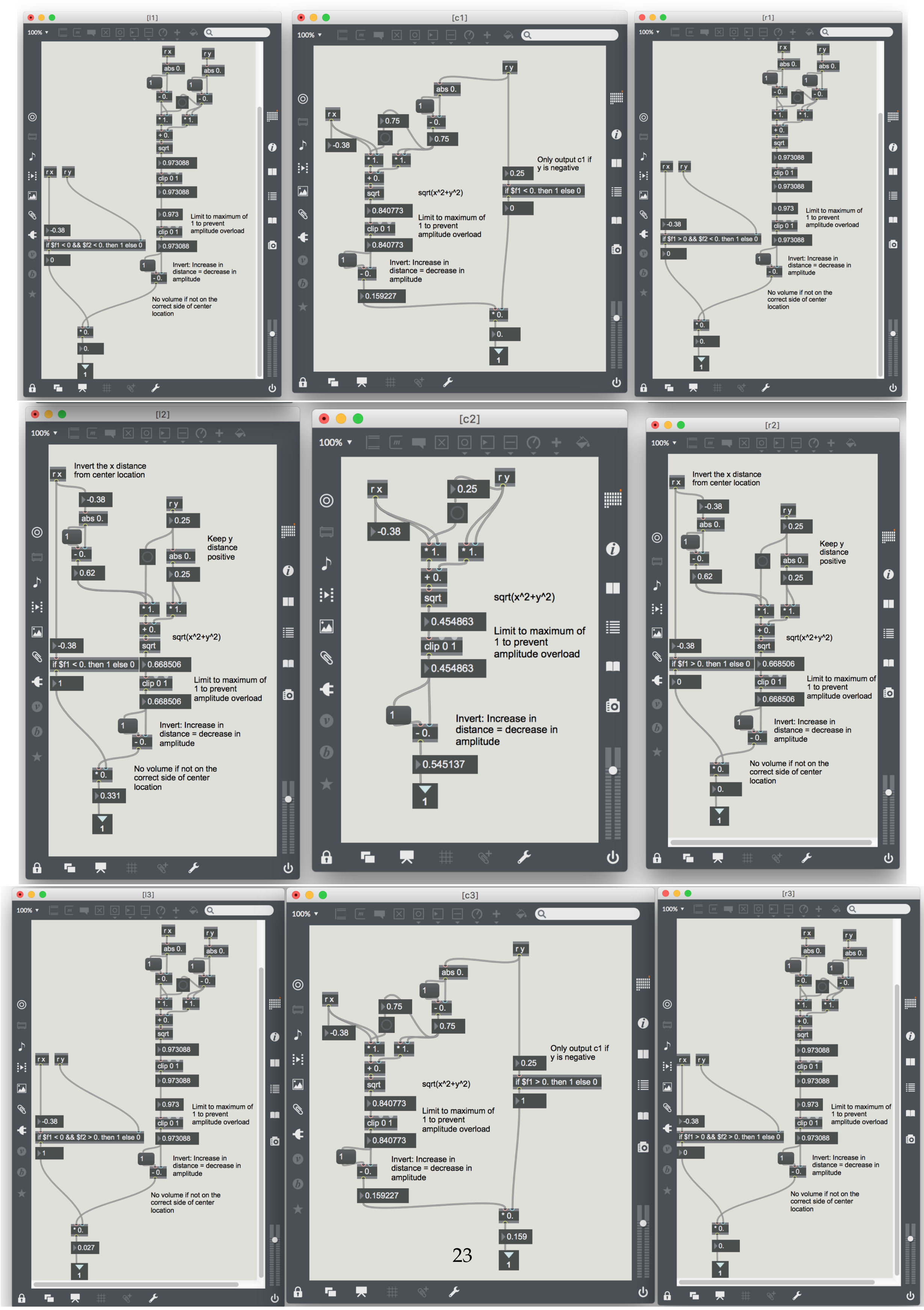


Figure 15: Overview of the individual panning algorithms used in iteration 1.

```
inlets = 5;
outlets = 5;

//Create arrays to store previous positions
var xArray = new Array(2);
var yArray = new Array(2);

var windowSize = new Array(2);

//Variables to use for file searching
var fileX, fileY, search;

//Defines how to split up the grid
var numberOfMeters;

//Loads appropriate files given users finger coordinates
function msg_int(input){
 if(inlet == 0){
  xPos = input;
 } else if (inlet == 1){
  yPos = input;//Add off set to start at (0,1)
 } else if (inlet == 2){
  windowSize [0] = input;
 } else if (inlet == 3){
  windowSize [1] = input;
 } else if(inlet==4){
  numberOfMeters = input;
 }

 //Split into sections
 if(numberOfMeters == 3 || numberOfMeters == 5){
  //Even grid for 3m and 5m
  xPosition = (xPos/windowSize[0])*(numberOfMeters);
  yPosition = (yPos/windowSize[1])*(numberOfMeters);
 } else if (numberOfMeters == 4 || numberOfMeters == 8){
  //4m separation requires different x,y coordinate scaling
  xPosition = (xPos/windowSize[0])*(numberOfMeters-1);
  yPosition = (yPos/windowSize[1])*(numberOfMeters);
 } else{
  //Extra row for others
  xPosition = (xPos/windowSize[0])*(numberOfMeters);
  yPosition = (yPos/windowSize[1])*(numberOfMeters+1);
 }

 //Round to nearest value
 xSection = Math.round(xPosition);
 ySection = Math.round(yPosition);

 //Start the lcd grid sections from column 1 row 1 instead of column 0 row 0
 if(xSection == 0){
  xSection = 1;
 }
```

```
 if(ySection == 0){
  ySection = 1;
 }

 //Distance in % away from center of section
 xBetween = 2*(xPosition - xSection); //x2 to get 100%
 yBetween = 2*(yPosition - ySection);

 //Which RIR to load in centre location
 outlet(0,xSection);
 outlet(1,ySection);

 //Output panning values
 outlet(2,xBetween);
 outlet(3,yBetween);

 //Store current location
 xArray[0] = xSection;
 yArray[0] = ySection;

 //If either coordinate is changed search for new files
 if(xArray[0] != xArray[1] || yArray[0] != yArray[1]){

  if(xArray[0] != xArray[1]){
   //Store previous value
   xArray[1] = xArray[0];
   X = xArray[0];
  }

  if(yArray[0] != yArray[1]){
   yArray[1] = yArray[0];
   Y = yArray[0]
  }

  //Output user location within grid
  if(numberOfMeters == 4 || numberOfMeters == 8){
   fileNumber = X + ((numberOfMeters-1)*(Y-1)); //Requires different algorithm for 4m due to different grid shape
  } else {
   fileNumber = X + ((numberOfMeters)*(Y-1));
  }
  outlet(4,fileNumber);
 }
}
```

Sections/Appendix/AppendixA/Code/loadFilesLogic.js

APPENDIX D

Test Participant Form

You have volunteered to partake in two user tests that should take no longer than 30 minutes to complete.

Test Descriptions

The VSS (virtual singing studio) is a system that is used to simulate the acoustics of another room. The system can be used by standing in the centre of the speaker array and singing into a head mounted microphone. By wearing the provided head-tracking device, you can turn in the virtual space by turning your head/body.

Test #1

This test aims to investigate the perception of movement within the virtual acoustic environment when using two different methods: Method **A** and Method **B**. You will be asked to step inside the VSS and say the word "Bob". Your location within the virtual space will then be changed and you will be asked to produce another sound. This process will then be repeated a second time but this time using method **B**. You will then be asked to state whether method **B** felt like you had:

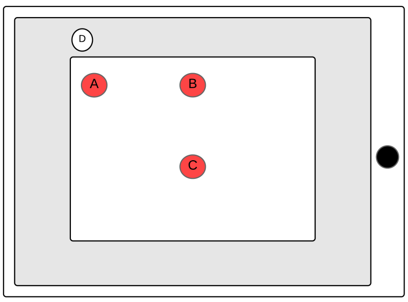
Moved a **shorter** distance than I had in **A**
Moved the **same** distance as I had in **A**
Moved a **further** than I had in **A**
I don't know

This process will be repeated 5 times in total.

Test #2

Part 1: You will be asked to step inside the VSS and to sing or produce a noise. After a short amount of time you will be asked to do the same again. You will then be asked whether you feel you have changed location or not with a simple Yes/No answer. This will be repeated 8 times.

Part 2: In this part of the test, you will be asked to change your location within the virtual space yourself by tapping on a location or dragging your finger around the iPad provided for you. You will be asked to rate on a scale of **1 - 10** how free you feel you can move about the room with **1** being a *jumpy movement* and **10** being *complete freedom to move without limitations*. You will also be given the opportunity to add comments to further explain you score if you wish.



To the left is a diagram of an iPad. **A**, **B**, and **C** indicate where parts of the room can be located. When situated in the VSS, you will start in the center of the room **(C)** facing towards the front of the room **(B)**.

A = Top left corner of the room
B = Front of the room
C = Centre of room
D = Button to calibrate head tracker

Answering Question

Note that when you're within the VSS it will be difficult to write down your answers to the questions asked. Therefore you will be asked to answer verbally and your answers will be taken down for you. You will be asked at the end of the test to check that your answers have been taken down truthfully.

Information and Consent

Experimenter: _______________

Please read the following statements and tick the boxes on the right hand side to indicate that you understand and agree.

I understand that at any point I may choose to withdraw from the experiment	□
I understand that I may omit answers to any questions	□
I agree that I am here voluntarily	□
I understand and agree that the experimenter conductor will be observing the experiment	□
I agree that the system being used has been explained to me	□
I agree that the point of this experiment has been explained to me	□

Participant Signature: _______________

Answer Sheet

Participant Number: _______________ Date: _______________

Test #1

Question 1: Please state whether you feel you have:

Moved a **shorter** distance than I had in **A**
Moved the **same** distance I had in **A**
Moved a **further** distance than I had in **A**
I don't know

Trial	**Score**			
	Shorter	Same	Further	Don't Know
1	○	○	○	○
2	○	○	○	○
3	○	○	○	○
4	○	○	○	○
5	○	○	○	○

I agree that the answers that have been taken down on my behalf are correct □

Participant Signature: _______________

Participant Number: _______________ Date: _______________

Test #2 - Part 1

Question 2: Do you feel you have changed location within the room?

Trial	Answer
1	YES/NO
2	YES/NO
3	YES/NO
4	YES/NO
5	YES/NO
6	YES/NO
7	YES/NO

Test #2 - Part 2

Question 3: Please rate on a scale of **1 - 10** the mobility within the virtual space where **1** = Extremely "jumpy" movement and **10** = Completely smooth movement or please select "N/A" if you can not tell you are moving.

Trial	Score										N/A
1	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
2	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
3	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
4	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
5	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○

Comments:

I agree that the answers that have been taken down on my behalf are correct ☐

Participant Signature: _______________

Question 4: Please rate on a scale of **1 - 10** the mobility within the virtual space where **1** = Extremely staggered movement and **10** = Completely smooth movement or please select "N/A" if you can not tell you are moving.

Trial	Score										N/A
1	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
2	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
3	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
4	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○
5	1 ○	2 ○	3 ○	4 ○	5 ○	6 ○	7 ○	8 ○	9 ○	10 ○	○

Comments:

I agree that the answers that have been taken down on my behalf are correct □

Participant Signature: _______________

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APPENDIX E

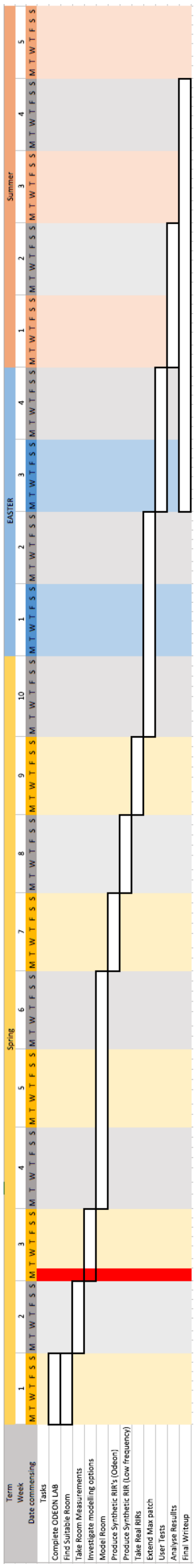

Figure 16: Initial Gantt chart showing the approximate time allocated to each of the tasks required to complete the project. The red line shows the time at which the Gantt chart was abandoned for a more appropriate planning method

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