Listening Chairs: Personal Acoustic Space in Public Places

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Abstract

Creation of a personal acoustic space for listeners of audio works in a public venue, which encourages the listener to focus and engage with the musical work, is the primary goal of this collaboration. Considering the context of this artificially created acoustic space various subsidiary goals are also important. These include visual aesthetics, as well as the audio capacity of the employed technology, while considering the portability of the equipment and the overall cost.

Introduction

The primary goal of this collaboration between engineer and composer is to create an environment in which listeners of audio works are encouraged to focus and engage with the musical work. The type of environment we are seeking to create is a personal acoustic space within a larger public venue. Despite the apparent simplicity of the goal there are underlying philosophical questions about the relationship of listener to sound works and the environment in which these works are presented, as well as the numerous technical questions and challenges we have met along the way.

This paper is an interim report on a work in progress. It will outline the context of this collaboration, make explicit the underlying philosophical assumptions for the project, and describe the process of designing and creating a new piece of equipment, with regard to optimising both the quality of the audio reproduction and the capacity to duplicate the equipment with regard to the overall cost.

While we describe the final goal of the project as an installation, we use the word in a rather abstracted way. Usually artists will use the word installation to refer to a specific genre of visual art, which may also include some sound or musical elements to create an alternate environment to the one in which it is physically located. Usually this new environment is an attempt to communicate the artist's conceptual ideas on a particular theme. We take the notion of creating a smaller environment for a specific purpose, and so use the word 'installation' to describe our project. However, it should be noted that we are using the concept quite abstracted from any specific music or sound that may be reproduced through the system.

As we come from different but overlapping backgrounds this collaboration has also been conducted in a spirit of enquiry into how other disciplines function with regard to their research and approach to technology.

Context of This Collaboration

Wendy is a composer of both acoustic and audio works, currently undertaking doctoral studies at the University of Wollongong. One of her interests is the presentation of her work in an accessible environment, which enhances understanding and focus on the work, while maintaining the integrity of the work itself.

It is not possible to work in the audio domain without having to learn something of the underlying technology and underlying theoretical concepts, even though the primary focus of my learning in this field is for creative purposes.

My compositional background in both contemporary classical music and experimental music has led me to explore a number of different compositional techniques, including sonification. This lead to my meeting of Eva at the ICAD conference in Sydney in 2004.

Eva is a telecommunications engineer specialising in digital speech and audio processing, with an underlying passion for music. Her doctoral research investigates the extraction of spatial information from multi-microphone speech recordings in reverberant environments. In parallel with researching in and developing new audio engineering technology and processing techniques, Eva questions and experiments with the importance of spatial sound in human experiences and how sounds correlate to certain environments. Eva's interest in 3D audio recording and reproduction techniques has uncovered a curiosity about acoustic space, 'surround sound' contemporary compositions, and how composers and engineers view and treat the roles of acoustics, space, and their listeners.

Philosophy and Design Requirements

Listeners in concert halls are automatically given the opportunity to be focussed on the music by fact of being in the concert hall environment. The characteristics of the concert hall which encourage listener focus are: 1. a defined space into which an audience member enters with the intention of listening to music; 2. the audibility of the work, including lack of background and distracting other sound; 3. seating for listener comfort; and 4. low levels of visual stimulation or distraction. Indeed often the only visual stimulation are the performers.

Some other composers have worked on solutions to the problem of providing a particular acoustic space for listening to audio works. For example Francoise Bayle created the Acousmonium, a loudspeaker orchestra, in 1974 at the Groupe de Recherches Musicales (GRM) in Paris. The Acousmonium contained eighty speakers of different sizes placed across a stage at varying heights and distances. Their placement was based on their range, their power, their quality, and their directional characteristics. This essentially replicates the concert hall situation replacing the performers with speakers.

Our philosophy of making music more available to a wider audience led to the concept of bringing audio works to a public space in a comfortable yet personal listening environment. Such a listening environment would not then be an experience limited to those who can afford to attend or reach museums, concerts, or similar venues generally located in metropolitan areas.

Previous works exploring seated personal acoustic space in public places include Bernhard Leitner's 'Firmament' (1996), which provided a six speaker 'symmetric' listening environment for a seated listener. Although the speakers are focused to provide an exploration of zenith, the installation is not flexible for different listeners and the leakage sound is likely be noticeable due to the open arrangement of the speaker array. Ros Bandt's outdoor work, Listening Place (2003), utilises underground speakers to present spoken stories to listeners seated on a park bench. Creating a diffuse soundfield, the installation is site-specific and is thus not easily portable. Iain Mott's 'Talking Chair' (1994) interactive installation places the listener in an immersive six-speaker personal soundfield. Although the shape of the 3D soundfield is wirelessly controlled by the listener, the sound is quite diffuse (and needs to be for 3D spatialisation) and the physical structure not flexible or easily portable.

To fulfil our philosophy of providing personal acoustic space in public places, the installation must be as flexible as possible, in order to be able to accommodate a variety of venues, and acoustic environments (including the outdoors), and listeners of varying physical dimensions and abilities. In addition, the installation can be used to present any stereophonic audio work so the design is independent of the audio composition for maximum flexibility in this dimension. Thus, our work may be considered as presenting a flexible and comfortable stereophonic playback system This distinguishes our work from these earlier chairs which are specially designed sound art installation encompassing a fixed physical structure which integrates with the specific audio work being presented.

We have chosen to focus on stereophonic audio output for the creation of an intimate, personal soundfield for the listener. This is still the most commonly available audio format for general use, enabling use of off-the-shelf components in the construction of the installation. However, there is no philosophical, design, or practical reason why more speakers cannot be deployed around the listener for surround sound. In fact, this is a future extension of the installation. We chose to use speakers over headphones due to listener comfort, freedom of movement, and most importantly, engaging the listener in a personal acoustic space that is not isolated from the greater public space. In this way, the listener is still part of the public space, rather than isolated in an individualised virtual acoustic space created by wearing headphones.

The installation also aims to address issues of presentation of audio works and how they are consequently consumed by listeners. Often, audio works are presented in museums, galleries or other public spaces where the listeners are limited to enjoying the works in passing, as there is no seating available to offer a comfortable means to engage with the work. Our philosophy considers the listener and their comfort as an intrinsic part of the installation. However, one assumption is made about the listener: that a seated position is more comfortable and conducive to engaging with the audio work than a standing position. As concerts traditionally offer seating (before moshpits and dancefloors became fashionable!) and people generally listen to music seated, we do not consider this assumption to limit the installation.

Considering the listener and listener comfort as central to our installation also raises questions about how the listener is perceived and accounted for when acoustic spaces are discussed in general. Are listeners considered part of the acoustic space? Conversely, without listeners, what does an acoustic space mean? Often, engineers overlook the listener's experience in favour of technical specifications for acoustics, such as room reverberation characteristics. Alternatively, how often do (or should) composers decide upon and compose for a specific acoustic space or simply leave such considerations to a museum curator or concert manager for maximum flexibility in presentation of the work? Or are characteristics of an acoustic space part of creative expression and thus part of the composition?

Installation Technical Design

Our philosophy considers the listener to be central to acoustic space. Thus, the listener's comfort and experience is one of the primary motivations behind the installation concept and design. A second, equally important motivation, is to bridge the 'musical divide' by assisting in making art music more available to the general public by creating a personal listening environment located within a public space.

Current research in, and commercially available products for, directional, focused sound reproduction address the issue of creating a personal acoustic place in a public place with variable levels of success depending on the technique: beam-steering, reflector-based, or ultrasonic.

Beam-steering, adopted from antenna theory and sonar, is a large-scale approach, that steers sound in a particular direction: manipulation of the magnitude and phase of each loudspeaker arranged in an array steer the sound in a particular direction by controlling where the sounds sum or cancel. The most common loudspeaker arrangement is linear, which allows for beam-steering in the plane perpendicular to the array. Two-dimensional loudspeaker arrays extend the capabilities to focusing sound in both planes, potentially converging to a central focal point. The advantage of the beam-steering systems (Duran Audio, EAW, Meyer Sound) is that the frequency response is adopted from the loudspeakers in the array (so high fidelity is possible); the disadvantages are variation in frequency response with the radiation pattern and the cost involved with the number of loudspeakers and multichannel hardware required

Reflector-based technologies apply the theory of satellite dishes to use curved reflective surfaces to amplify or direct sound in acoustic bandwidths (Wahlström, 1985). However, the frequency response of the system is variable and highly dependent on the curve size and shape e.g., parabolic, hemispheric, or a hybrid of various shapes; the amplification is greatest with high frequencies due to the shorter wavelengths. Parabolic reflectors (MuseumTools, Meyer Sound), although achieving a greater range than other shapes, cannot create stereo images, whereas hemispheric and hybrid sound domes can create virtual stereo imaging through an audio 'hologram' at the listener's ears (Brown Innovations, SoundTube Entertainment). The main advantage of these systems is the low cost (relative to other focused sound approaches) and ease of use.

Adopting techniques from AM radio propagation, using ultrasonic frequencies to modulate audible sounds relies on the nonlinear interaction of sound waves in air: two frequencies emitted in close proximity will generate secondary signals at their sum and difference frequencies (Yoneyama et al., 1983; Pompei, 1998). Thus, when ultrasound is modulated by an audio signal and transmitted, the nonlinear wave interactions through propagation in air demodulates the ultrasound signal to recover the original audio. To achieve focused sound, wave propagation theory states that the source directivity depends on the size of the source compared to the emitted wavelengths. Thus, due the short wavelengths of ultrasonic signals, the sound propagates in a narrow beam – ideal for focused sound. The disadvantages of ultrasonic systems (Holophonic Research Labs, American Technology) are that, due to the direct sound beam, the apparent sound source is inside the listener's head; and, stereo images cannot be produced as coherently combining two beams is non-trivial.

Figure 2. *Prototype of one component for one listener.*

The technique most comparable and relevant to the goals of our project are hemispheric or hybrid reflectors (e.g., the Localizer from Brown Innovations or Focus Point Speakers from SoundTube). Hemispheric or hybrid reflectors are the only small-scale, focused sound technology to support stereo imaging – spatiality, in addition to directivity in a personal acoustic space. While these objectives are central to our goals., the use of such commercially available products in our installation is currently limited by budget and, quite significantly, the frequency and polar response characteristics. Although the Localizer and FPS bandwidth encompass the audio range (approx. 150Hz - 20kHz, +/-3dB), the low-frequency attenuation is significant, and the frequency response is not as flat as conventional speakers, with resonant peaks clearly exhibited. In addition, polar radiation patterns can vary greatly with different frequencies. However, adopting the technical concepts of hemispheric reflectors for a more sophisticated playback system is a potential future avenue for this work.

The challenge is then to map our philosophical questions and subsequent design requirements into a physical installation, using equipment of optimal reproductive capacity. Ease of use (for the listener and curator), ease of reproduction of components, portability, visual aesthetics, acoustic quality, and overall cost are the key design drivers; how each of these physical, visual, and acoustic design constraints were addressed will be discussed in more detail.

Physical Design

The installation conceptually consists of four armchairs placed in a square facing outwards, with each chair sporting a pair of small stereo speakers adjustable to head height, enclosed in an adjustable floor based housing located behind the chair. Figure 1 conceptually illustrates the arrangement of the chairs.

Figure 2 illustrates one prototype component,

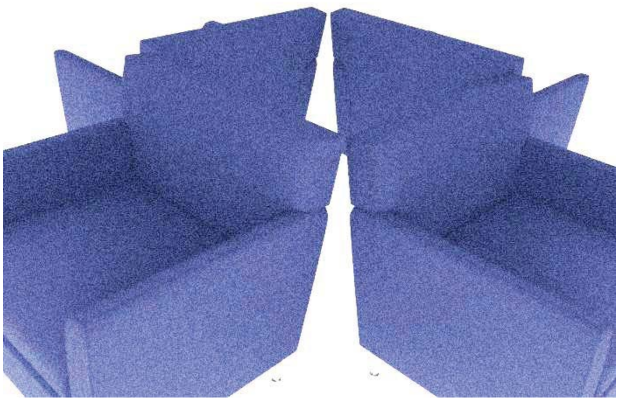

Figure 1. *Arrangement of the chairs.*

that is the arrangement of elements for one listener. Each chair has an independent audio source: the speakers are connected to an out-of-sight portable CD player.

The audio flow path and interaction between installation components is shown in Figure 3. It will be necessary to provide a power source for the audio hardware (speakers and CD player). To accommodate for a range of venues, this power source can be a 240V wall outlet for indoor installations, or we can also work with portable power sources for the outdoors (e.g., solar power or batteries) with minimal alterations to the technical design.

For aesthetics, ease of use, and ease of producing a number of sets of the components (by using 'off-the-shelf' equipment), a floor lamp was chosen for the speaker housing. The decision to use floor lamps to hold speakers is a result of many attempts to custom-design speaker housing that could be mounted onto the back of any armchair. However, having customised mounts limited the ease of duplicating the system, since each would need to be individually made by a technician. In addition, designing a mount flexible enough to accommodate a variety of chairs proved quite difficult. Thus, a floor-mounted option was selected as this has only one requirement: that floor space is available behind the armchair.

The particular floor lamp model used (Austrabeam Glee 32336 in black), shown close-up in Figure 4, was selected based on cost, having a pair of separable lampshades, lampshade shape and size (to hold the speakers), ease of re-cabling, flexibility (to accommodate different chairs and listeners), and portability (the lamp can be dismantled and flat-packed).

Flexibility is a major concern as chairs and listeners can vary in width and height, and listeners will vary in seating position e.g., slouching. Thus, flexible lamp components, such as the long 'goosenecks' used to connect the lampshade to the lamp body (see Figure 4), are ideal for accommodating these requirements. We are currently sourcing goosenecks to use in the lamp body to add further flexibility to the physical design.

In summary this physical design meets the requirements of having the:

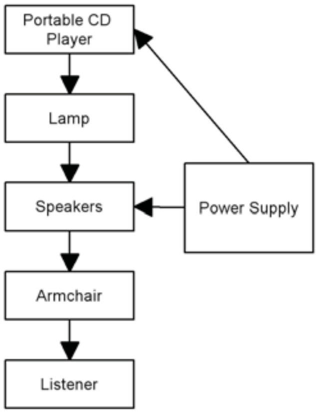

Figure 3. *Block diagram of audio signal flow and installation components*

- Listener central to the acoustic space;
- Listener comfort intrinsic to each component;
- Creation of a personal acoustic space in a public space. Note that we can only control the personal acoustic (sub) space, and that we assume nothing of the ambient, greater public space.
- Flexible enough to accommodate a variety of listeners' physical requirements.
- Is relatively easy to duplicate the component parts.
- Is portable and can be used in a variety of environments.

Acoustic Design

Acoustic quality is obviously of utmost importance in an audio work. However, cost, ease of duplication, matched acoustic responses, and size can severely affect technical characteristics such as frequency response (esp. at low frequencies) and

Figure 4. *Speaker housed in lampshade with acoustic insulation and gooseneck connection*

audio clarity, tonality, and distortion (esp. at loud volumes).

To continue using 'off-the-shelf' equipment for ease of duplicating each component, several pairs of (cheap) computer speakers were tested for their trade-offs in technical characteristics, as listed above, and evaluated subjectively by the authors with a range of audio sources. The Altec Lansing 120i model, being a pair of 3 watt, 4 ohm speakers, was chosen due to its low cost, audio quality, availability of power, volume, and tone controls on the circuit board, and easy dismantling from its casing to re-cable for fitting in the floor lamp. The speakers have a frequency response of approx. 85Hz to 18kHz, a range that we would consider to be suitable for most audio works.

The creation of a personal acoustic space (or small 'sweet spot') requires the soundfield to be concentrated at the listener's head i.e., between the two speakers. This is the main acoustic design reasons we chose to use the floor lamp in Figure 4. The diameter of the lampshade snugly fit our speakers with a shape and length ideally suited to direct the audio towards the listener's ears and minimise sound diffusion.

To further reduce sound diffusion, beyond the directionality provided by the speaker mounting, the rear and inside of the lampshades were lined with flexible but dense polyester building insulation. Adding insulation to the inside of the lampshade served two purposes: it reduced acoustic reflections (i.e., reverberation inside the metallic lampshade) to give a clearer sound; and, minimised acoustic leakage from the patterned holes at the edge of the lampshade, presumably present for visual aesthetics and light diffusion.

Small movements made by the listener's head out of the 'sweet spot' results in a significantly different soundfield, as verified by our pilot listening tests, discussed in the next section. Such a personal soundfield in a comfortable environment allows the listener to focus on the musical work as their physical needs are accounted for. Although the acoustic design maximally contains the optimal soundfield to the space between the speakers, some sound leakage is allowed such that passers-by can hear enough to rouse their aural curiosity.

While some small leakage may assist in attracting their attention, in order to make the installation as flexible as possible, each listener will automatically hear the audio work from the beginning when they are seated. We are still investigating how build in an automatic reset function for the sound when the listener is seated. We would like the reset to occur as the listener's head is located between the speakers.

Although we have devised a concept for this part of the project we have not yet begun to build the required electronics. The technical concept is to use infrared (IR) sensors in the two speakers, and as soon as the listener's head enters the soundfield (i.e., breaks the IR beam between the speakers), this triggers the reset function on the audio source (CD player). Minimal electronics are required for this concept, and with some tweaking of electronics we hope to incorporate the extra components as add-ons to the CD player circuit boards.

Visual Design

The use of these floor lamps is thought to be aesthetically pleasing, while also playing with the expectations of the audience who may be intrigued by the notion of sound emanating from a lamp shade. Although the work focuses on the aural senses, the importance of visuals cannot be overlooked. Due to the philosophy of the work requiring a personal soundfield, only softly audible, intentional 'leakage' audio can be heard by passers-by. Thus, potential listeners passing by the installation are more likely to be drawn in by the visual appeal, only hearing the 'leakage' audio at close range. Hence, a visually aesthetic installation is paramount in attracting potential listeners to engage with the audio work. This is one of the key motivations behind using 'off-the-shelf' equipment in non-traditional ways: this naturally draws in people's curiosities.

Far-field visual aesthetics are essential in this work to bring in listeners; however, there must be minimal visual distractions for the listener once they are seated. As visuals can easily distract a person from their aural senses led to the physical arrangement of chairs shown in Figure 1. With the rest of the installation and other listeners out-of-sight from the listener, each listener is minimally distracted from engaging and experimenting with the aural stimulus presented by the installation.

Listening Tests

We conducted a pilot study on four listeners who simply happened to walk past our installation. A number of physical requirements, especially in regards to flexibility for accommodating different chairs and listeners, were brought to our attention from these informal listening tests using untrained listeners.

Physical design issues highlighted during listener tests include: 1. Listener sitting position: although this can be seen as an unexpected acoustic discovery! Slouching in the armchair and focusing the speakers downwards towards the ears results in a completely different listening experience (and more comfortable for some)! 2. Listener height variation even when seated is significant. This requires wide flexibility in the positioning of the speaker mounting.

The main acoustic design issue highlighted by listening tests was surprise at the concentrated soundfield, which indicates that the overall concept of encouraging potential listeners to be seated to engage with a personal acoustic space is worth pursuing.

This pilot study was really useful in highlighting some features of which is we were ignorant. And we intend to conduct more tests iteratively for maximal listener feedback as we proceed with the project. In particular, we will seek comments regarding our assumptions about listener comfort, portability, flexibility and the general acoustic experience of the listener.

Extensions and Future Work

1. Auto reset as the listener engages with the installation.
2. Listener control of audio (start/stop/reset/volume).
3. Testing multiple sets of components out in field.
4. Investigating alternate power sources such as solar power.
5. Testing in anechoic chamber (an unnatural public space)
6. Possible extension of work: surround sound with lamps in a circle around the seated listener.

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