ACMUS:
Design and Simulation of Music Listening Environments

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Abstract. *This paper describes an interdisciplinary project on room acoustics. The main goals of this project is to identify and analyse the relevant acoustical parameters for small rooms used for music production – concert halls, studios, lecture rooms, movie theatres, etc. – and, using modern methodologies for software development, build computational tools to evaluate and manipulate these parameters. We describe a computational environment - ACMUS -which will provide tolls for measuring acoustical parameters in small rooms, and for simulating the acoustic behaviour of those rooms.*

1. Introduction

In the last 30 years, novel procedures and technological innovation in music production has set forth the necessity of greater interaction among musicians and technicians of other areas, such as sound engineering. Our contact with music production is more and more mediated by different technologies (recording process, speakers, sound systems, etc.) and this makes evident the need to bring together the corresponding areas.

There are very few research initiatives in Brazil related to what could be named “musical acoustics”. The projects we have found are related to civil engineering and architecture rather than to specific issues related to music listening. Despite the many laboratories devoted to research in music technology that have been created in the last decade, musical acoustics has been taken into account in rare situations. However, this should not be regarded as indicator of a lack of prepared human resources or of interest in this issue. Indeed, many isolated efforts to solve problems related to musical acoustics can be found in several universities.

Recently, a field frequently called “room acoustics” has received attention given the demand for projects of recording studios, home theatres and movie theatres. Many companies have come to supply this demand in Brazil, but they have used imported technologies and procedures.

The Departments of Music and of Computer Science at the University of São Paulo have initiated a joint project to organise an interdisciplinary research group in musical acoustics. Our goal is to congregate individual initiatives and to mediate artistic production and technical issues that support present day music production.

This interdisciplinary project shall bring together experts in music, computer science, architecture and acoustics. The unavoidable methodological difficulties of organising such a diversified research team shall be controlled by the selection of researchers with large experience in their specific areas as well as some solid experience in other areas related to the project. It is also important to limit the scope of the project and their related sub-areas, avoiding the consideration of problems that, although interesting, may be beyond the capabilities of our research team.

2. General Goals

The main goals of this project is to identify and analyse the relevant acoustical parameters for small rooms used for music production – concert halls, studios, lecture rooms, movie theatres, etc. – and, using modern methodologies for software development, build computational tools to evaluate and manipulate these parameters. This shall be the starting point to generate tools to simulate and support the design of environments for music listening.

3. Specific Goals

- To analyse the relevant parameters for quality assessment of small rooms used for music listening and recording.
- To develop the prototype of a computational system – the ACMUS system – for (a) measuring and evaluating acoustical parameters in small rooms, (b) simulating the acoustic behaviour of those rooms, experimenting with specific features such as geometry, acoustic absorption of walls and surfaces, positioning of sound sources, expected use of each room, etc.
- To build software tools to design new musical environments and improve the behaviour of existing ones. These tools shall be developed using advanced component-based software technology in order to build a flexible, extensible and adaptable system. The software shall be made available for musicians and sound engineers interested in using its capabilities as well as for programmers and computer scientists interested in creating new components to extend its functionalities and customize it to different situations. In that manner, we seek to foster the development of an "open community" of research in musical acoustics.

4. Project Description

Various factors influence what we hear in a room. Controlling these factors is fundamental to determine what we hear in situations such as concerts, recordings, electroacoustic music performances and listening of pre-recorded material. D'Antonio & Cox (1997: 2) indicate as critical factors: "the quality of the electronics, the quality and placement of the loudspeakers, the hearing ability and placement of the listener, the room dimensions (or geometry, if non-cuboide) and the acoustical condition of the room's boundary surfaces and contents".

In the design of many environments for music listening these factors are not carefully taken into account. In other cases, the designers do not deal properly with the interactions among those factors. Moreover, the complexity of these interactions quite often has led to costly solutions based on trial-and-error procedures to evaluate them.

As an example, we can have distortions that result from ill coupling between the listener and loudspeakers in an electroacoustic concert, a recording studio, or a residential room. One must take into account the interaction among the sound sources, the listener, and the room so that unfavourable interferences do not occur. In other cases, an unbalanced sound distribution between primary sound sources and reflected sound can lead to disastrous effects.

This project is composed of three modules, to be developed independently. Nevertheless, we regard as of great importance that they are integrated in the end as a single system – the ACMUS system. The modules are:

4.1. Module I – Generation and Measurement of Acoustic Signals

This module shall be devoted to the development of computational components to generate specific audio systems and compare them with recorded signals from sensors (microphones) within a room. The signals generated shall include white noise, pink noise, sinusoidal, pulse and transient signals. The recorded signals shall be compared to the generated ones by means of graphical interfaces and semi-automatic analytical tools.

These measurements shall provide information about the acoustic behaviour of rooms. The most important measurement is Reverberation Time, or RT60 [Schröder, 1965; Beranek, 1962; Polack, 1992]. This is a determining factor of the quality of a room and indicates how long a sound takes to decay 60dB once the sound generation is interrupted. These measurements are usually made with pink noise, and the RT60 are calculated for different bands in the audible spectrum. The pattern for these bands is 1/3 of octave, what means 31 bands between 20 Hz and 20KHz (the human hearing range).

Another important measurement is a room's frequency response. It can be generated with a reference (pink noise) signal. The sound in the room is then captured and the result is presented as an amplitude versus frequency graph. With this we have the characterisation of the acoustic response for different frequencies, and acoustic problems in the room can then be identified.

4.2. Module II – Acoustic Simulation

This module is the central piece for the project. It shall permit the simulation of the acoustic behaviour in various environments and situations. These simulations will help in the design of acoustical environments (rooms, theatres, studios, domestic rooms, lecture halls, etc.), detecting problems and proposing solutions. The software will support the design and restructuring of specific rooms to achieve specified acoustic results [D'Antonio & Cox, 1997; Vian, 1986; Warusfel & Cruz-Barney, 1995; Rindel, 1997, Rindel, 2000]. Several factors can be controlled to optimise the quality of music listening environments, by means of distributing loudspeakers, placing the listeners with respect to the sound sources, selecting appropriate material for the room surfaces, and even determining the geometry of the room.

We are interested in what has been called "small rooms". Although the physical processes involved in the acoustics of small and large rooms are similar, the parameters and value ranges for each of these cases are considerably different (see e.g. Beranek (1992); Anders (1990)) and will not be addressed in the initial phases of this project.

The software developed in this module shall support the following:

- Computation of the relative positioning of sound sources and listeners in a room. In small rooms, the loudspeakers are close to reflective surfaces, thus generating distortions and sound diffusion [Everest, 1981, Ballagh, 1983]. The modes of resonance of the room and the coupling between the position of the listener and of the sound sources can generate distortions of up to 15dB for certain frequencies in specific points in the room. The software shall indicate the optimal positioning of sound sources and listeners inside the room using combinatorial optimisation algorithms, such as simulated annealing, or some continuous optimisation techniques, such as real-valued constraint propagation.

- Optimisation of the geometry of a room. Each room has a certain number of modes of vibration in specific frequencies. If many of these modes coincide for a specified frequency, distortions can occur by the amplification of some frequencies and the attenuation of others [Bonello, 1981]. The estimation of the vibration modes is relatively simple, but the interactive optimisation of the geometry of a room with respect to these modes can be computationally expensive. The software shall be capable of performing these optimisations efficiently.

- Simulation of absorption coefficients for rooms. The acoustical characteristics of a room are determined not only by its geometry but also by the absorption coefficients of its internal surfaces (walls, etc.). By using pre-determined absorption coefficients for different materials [Beranek, 1993], we can infer many features of a room, including its Reverberation Time (RT60). Alternatively, given desired features and values for the desired RT60 of a room, we can suggest the material for the room surfaces.

- Three-dimensional mapping of the acoustical behaviour of a room. With a graphical "map" of a room's acoustics, we can visualise the behaviour of each spatial point within the room, with respect to modal analysis and reverberation times for each frequency.

- Schröder diffusers. The resonance modes for lower frequencies (up to 300 Hz) are important for the acoustic characterisation of a room. On the other hand, for medium and high frequencies the diffusion and reflection patterns are of great importance [Rindel, 1995]. Ideally, the overall acoustical quality of a room increases with the homogeneity of diffusion factors. In order to solve the problem of the lack of reflection from side walls in concert rooms, Manfred Schröder designed a highly diffusing surface [Schröder, 1975; Schröder, 1984; D'Antonio & Konnert, 1983 D'Antonio & Konnert, 1984]. This surface can be used in situations that require critical hearing conditions (e.g., concert rooms or recording studios). Using Schröder diffusers, one can have a uniform distribution of the acoustic reflections within a room. They consist of evenly distributed wells on a surface, each well with a different depth. The distribution patterns for the wells and their depths are obtained as function of the frequencies occurring in the room. This software shall provide support to design Schröder diffusers.

4.3. Module III - Toolbox

We intend to develop various software tools for musicians, sound and audio engineers, architects, etc. These tools shall include:

- Audio and acoustics calculator (wave lengths, conversions pitch/frequency, phase cancellation, delays, sampling rates for digital audio, etc.);
- ITGD (Initial Time Gap Delay). This is a decisive factor for the acoustic quality of an environment. In order to control the ITGD, one should avoid that the first reflections reach the hearer in intervals smaller than 20 milliseconds [Davis, 1979]. This is of particular importance for small rooms in which reflective surfaces are too close to the listener, thus making that the reflected sound reaches the hearer immediately after the direct sound. In recording studios, for example, one can solve this problem using the concept of LEDE (Live End Dead End - Davis & Meekes, 1982; Davis & Davis, 1980], in which half of the room – where the loudspeakers and the sound engineer are placed – is designed to avoid primary reflection, and the other half is designed to enhance diffusion.
- Spectrogram, oscilloscope, and phase measurement. These are basic tools for audio, acoustics, and room design.

5. Conclusion

The project ACMUS is at its initial stage. We understand it is important for many reasons:

- The software tools and systems that shall be generated within the scope of this project are potentially useful for architects, civil engineers, sound engineers, and musicians. We believe it can help improving the acoustic quality of small rooms as stated above.
- As a scientific endeavour, the project shall give room for the integration of several techniques – computational, physical, mathematical, and musical – in an original fashion, producing interesting results originated from the interaction among these techniques and areas.
- The project shall also foster interdisciplinary research and integration within the University of São Paulo and the whole research community devoted to this field.

The project shall last for three years. We intend to experiment with the acoustic re-design of at least two rooms – a recording studio and a multimedia lecturing room at the University of São Paulo – to validate the tools and techniques we develop.

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