SPATIALIZER: FROM ROOM ACOUSTICS TO VIRTUAL ACOUSTICS
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ABSTRACT
Espaces Nouveaux and IRCAM collaborate on a common project named **spatializer**, directly stemming from previous researches in room acoustics. The perceived sound could be considered as a virtual acoustics processor. The concept of virtual acoustics implies the mastery of both objective and perceptual descriptions of the acoustical quality of a given listening situation. Acoustical quality can necessarily become a musically controlable parameter. The choice of the control parameters of the *spatializer* can be achieved by moving through a database of acoustical qualities or with the use of a perceptive/objective interface. The implementation of the spatialization task is achieved by a real time DSP module automatically configured by an acoustics expert module allowing several kinds of use interface.

1. VIRTUAL ACOUSTICS

1.1. A concept derived from room acoustics researches

Any sound event reacts according to the acoustical conditions around it. One can aim at promoting the acoustical-quality to the status of a musically controllable parameter, and consequently conceive rooms in which acoustical conditions could vary. Therefore one can either use a mechanically changing room (like, for example the Espace de Projection in IRCAM), or use an electroacoustic system (sound capture, diffusion, loudspeaker) that artificially recreates in the space the desired acoustical conditions. Controlling these kind of systems is based on a double knowledge: one has to be able to predict the acoustical changes that will be generated by the system, and to evaluate the perceptual effects induced by an objective change in acoustical quality. Both of these questions have been dealt with by the IRCAM room acoustics research team in the previous years. For acoustical prediction, a software has been developed which allows to characterize the acoustical quality of a place from the knowledge of its various surface components (geometry, absorption and diffusion characteristics) and of a description of the different sources involved (place, orientation, directivity), whether they are acoustical or electro-acoustical. In the domain of perceptual analysis, a study was achieved whose goal was to objectivate the various aspects of the perception of acoustical quality. Obviously acoustical quality is variously estimated by different people; however, the properties of the auditory perception founding such an estimation are close from one subject to another. Psycho-acoustic tests put in evidence for all subjects common dimensions in perception: these dimensions we call perceptive factors. Every factor can be numerically related to measurable acoustical criteria. This relationship allows the acoustician to give a perceptual interpretation of a measured estimation, and to control a variable acoustics system in a manner relevant to perception. This knowledge founds the concept of virtual acoustics, since an acoustical quality in virtual acoustics will be the description of a listening situation in the perceptive space (Jullien, 1992).

Consequently, a virtual acoustics system is a system allowing the control of the perceptive space, at least in part. This idea can be applied to a room - virtual room - in which the totality of the perceptive criteria relevant to room acoustics will be modelled, or to a given source - virtual source - in which the controlled aspects are the one related to the perception of this given source. A basic musical application would be to master the variable distance between the perception of an instrument (real or synthetic) and of a loudspeaker image of this instrument.

2. DEFINING THE SPATIALIZER

2.1. Definition of the tasks

2.1.1. Simulation and Diffusion

The *spatializer* receives, for any couple source-zone / listener-zone, a virtual acoustical quality called target-quality. Data fed into the *spatializer* are objective descriptions of the target-quality (here written $Q_{target}$) and of the sound sources

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used (real or synthetic), as well as the description of the diffusion system (external context here written C_{ext}). The Q_{target} is described with objective data — acoustical criteria. This description can be obtained from acoustical measures (if the aim is to recreate the acoustics of an already existing room) or from results of simulation (architectural acoustics), or from a description of perceptual factors (imaginary acoustics). The description of the target also includes the sound sources present into it, whether they are loudspeakers or musical instruments. When the space onsetage and/or the space for the listener is broad, the user can define several Q_{target}, each one corresponding to a different couple source-zone-listening-zone. A correct description of the diffusion system (C_{ext}) allows the user to characterize the effect of any loudspeaker on any listening zone, as well as the constraints imposed by the space in which the simulation actually takes place. Using these data, the spatializer computes the parameters regulating the various processes happening between the source (microphones or recorded/synthetic signal) and any given loudspeaker (these processes are here called P_{DSP}). This is the expert operation, here called C (Q_{target}, C_{ext}).

The simulation is achieved in an actual space, preferably anechoic, with a multi-loudspeaker sound diffusion system, called the diffusion environment. An ideal diffusion environment (an anechoic chamber with loudspeakers in any possible place) would theoretically allow the simulation of any possible acoustical situation. We will use for a good candidate of such an environment the Audiprotecte, located in Espace Nouveaux (Delage 1987).

2.1.2. Managing constraints

However a musician does seldom work in such a neutral space. This is the reason why limits (constraints) on the diffusion environment can be defined for the spatializer, allowing it to be adapted to places endowed with their proper acoustical qualities. The acoustical variation offered by the spatializer will of course depend on the possibilities allowed by the diffusion environment. Consequently one must verify the acoustical quality actually produced within the environment and the set of parameters P_{DSP}. This second expertise operation, called C^{-1}(P_{DSP}, C_{ext}), will compute the newly obtained acoustical quality, written Q_{est}, whose type is similar to Q_{target} but whose value is not necessarily equal. If one can dispose of a quasi-ideal diffusion environment during the preparatory stage, one can achieve Q_{est} as well as Q_{target} with the spatializer and so compare what is desired to what will be eventually obtained.

Technically speaking, the management of constraints will also permit to test the acoustical quality in other points than the one in which the Q_{target} is defined, and, for a given electro-acoustic setup C_{ext}, to test and compare between several rooms. Finally, for electro-acoustic music, one can tune-up the parameters of electro-acoustic diffusion in an ideal diffusion environment, simulating the constraints of the place in which the concert will happen. The setup found will later be exported to this particular concert place.

2.2. Musical and research project

The practical use ranges from the acoustical diffusion in a lab of, for instance, an anechoic recording of string quartet, simulating a given place in a given concert hall, to the acoustical setup of a multi-use (and consequently multi-acoustics) performance place. Otherwise, criteria of acoustical quality can be included in a musical composition (Beguhl 1990), and even be used in an interactive way in the case of an instrument interface connected either to the input parameters of the spatializer (Q_{target}), or directly to the P_{DSP} setting.

A benchmark for experimenting in psycho-acoustics is made possible by the achievement of the DSP modules for the spatializer. The achievement of these modules being one of the main priorities, some of these experiments have already started. They make possible to measure to what extent approximation can be made. For example, if the constraints for recording and diffuse signal for the reverberation field are well-known, for the first reflections, one knows less well how precise the directions of emission and reception must be respected. The prototype of the spatializer allows us to precise these points.

3. USER-INTERFACE

3.1. Objective criteria : measurements and simulations

The first user-control can be obtained with the use of a database of acoustical measures made in various rooms and concert halls (Wansfell-Jullien 1992). This database can be enlarged with new measures or with the results of simulations. Some points representing acoustical qualities can be chosen in this database. A multidimensional analysis can allow
the user to extract the most relevant differences between the chosen points, and to move along these axes, allowing an interpolation between acoustical qualities. Otherwise the user can control the system with a perceptuo-subjective interface (Bloch-Jullien 1990). The user can start from scratch with the perceptive parameters, or combine the perceptive approach with a preliminary research in the database, as described above, the results of that research being translated into the perceptive domain. Finally one can use the spatializer with a direct access to the DSP interface, connected or not to an instrumental interface. Once more the setup can be modified around a position calculated using the methods described previously.

4. Architecture

The spatializer is organized into two independent software components (see fig. 1). The first one - the Acoustics Expert - is a non real time module that takes a proper specification for \( \Omega_{\text{target}} \) and \( C_{\text{ideal}} \) as its inputs and then elaborates the signal processing parameters. The second component, a module specialized for fast signal processing, will perform the real time simulation depending on the configuration values made available by the expert module. The possibility of using this DSP module directly by an explicit control of its internal parameters will be preserved in order to provide soon with a convenient tool for the test phase of the DSP algorithms as well as psycho-acoustics experiments. Intuitive user interfaces, eventually defined in a perceptual domain (Bloch-Jullien 1990), will have to be designed. Their task is to feed the Expert with a acceptable representation of \( \Omega_{\text{target}} \) and \( C_{\text{ideal}} \) derived from the description given by the user.

The DSP module is structured into three stages (see fig. 2) respectively: sound capture, room effect computations (including patterns of first reflections and reverberation), diffusion (also in Begault 1990). Considering a single couple (source zone, listening zone), three set of signals have to be either picked up or computed: the direct sound (eventually leaved to the live instrumental source itself), some signals, used in the computation of first reflections, picked up in several directions around the source, and a power signal involved in the computation of the reverberation process. The latter may either be a combination of the previous ones or captured in a particular direction of the instrumented radiation (Warusfel 1990). Boundary reflections are simulated by one convolution module for each direction being considered (at least front, left and right). Then the output signals are mapped to every loudspeaker with a level (g) and a delay (i) specified by the expert module.
The IRCAM Signal Processing Workstation (ISPW, see Lindemann 1991) has been chosen as the hardware component of the Spatializer. It is built around a NeXT host, up to three Intel i860 coprocessor boards coupled with daughter boards allowing each 8 channels of digital signal. The DSP module is being prototyped with the ISPW version of Max (Puckette 1991). We envision to interface a scheme interpreter to the messaging system of Max in order to get an environment that would be convenient for programming prototype versions of the expert module. Later, when FTS (Puckette 1991), the real-time DSP server that leaves underneath Max, is made available, the expert and the specific interfaces will be realized as a stand-alone application being serviced by FTS at the same level than Max, thus giving rise to a spatializer distributed through three communicating processes.

Fig. 2 Processing for one source / one listening zone

5. REFERENCES

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