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THREE-DIMENSIONAL ACOUSTIC DISPLAYS IN A MUSEUM EMPLOYING WFS (WAVE FIELD SYNTHESIS) AND HOA (HIGH ORDER AMBISONICS)

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Abstract

The paper describes the sound systems and the listening rooms installed in the new "museum of reproduced sound", actually being built in Parma, restoring an ancient church. The museum is devoted to the exposition of a huge collection of antique radios and gramophones, but it will also exploit the frontiers of modern methods for immersive surround reproduction: WFS and HOA.
In the main hall, a large planar WFS loudspeaker array is employed for inviting the visitors to enter the world of sound reproduction, providing stunning effects and emotional sounds enveloping them from many directions.
At the end of the exposition path, a special HOA space is employed for showing the recent developments of recording/reproduction methods started from the Ambisonics concept, capable of creating natural reproduction of sport events, live music and other immersive acoustical experiences; in this room also a binaural/transaural system is available.
A second, larger listening room capable of 30seats is equipped with a horizontal WFS array covering the complete perimeter of the room. The paper describes the technology employed, the problems encountered due to the difficult acoustical conditions (the museum was formerly a church), and the novel software tools developed for the purpose on LINUX platforms.

1. INTRODUCTION

The "Museum of Reproduced Sound", beside the sound of ancient radios, tries to give to the visitors the views of some of the listening systems of the future.
The visit starts from the six niches in which old audio systems are displayed: a guided historical itinerary leads the visitor from ancient to modern systems, with the capability of listening recordings of them, which will make them to hear the evolution of the sound quality.

In the centre of the main room a “sonic chandelier” provides in a small area a spatial sound composition, with sounds and noises moving just above the head of the listeners.
In the ancient room behind the church, Stereodipole, Ambisonics and Wave Field Synthesis techniques are employed to demonstrate real 3D-sound, significantly beyond the capabilities of current surround systems (home theatre systems). The two rooms in which they are implemented are both didactical spaces for demonstrations, but also labs for listening tests.

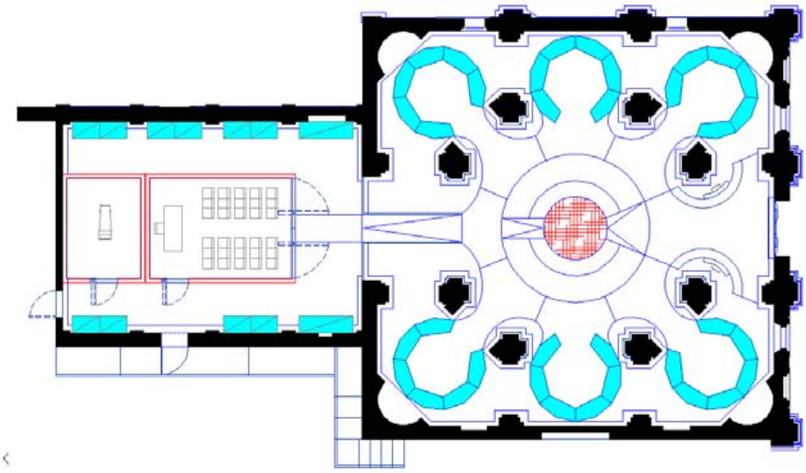

Figure 1. The map of the Museum of Reproduced Sound – the two listening rooms are on the left, the sonic chandelier is at the centre of the main hall

2. THE SONIC CHANDELIER

The “sonic chandelier” is an audio installation that permits to create virtual sound sources “dancing” above the head of the listeners. This object will introduce the visitors of the museum providing stunning effects and emotional sounds enveloping them from many directions. This result is obtained employing the Wave Field Synthesis theory, normally used for horizontal-surround effects, in a different and original way.
The chandelier is made of 228 wide-band speakers (Ciare PM120), grouped in 64 groups independently powered and processed, suspended at an height of 4 meters as shown in Fig.2.

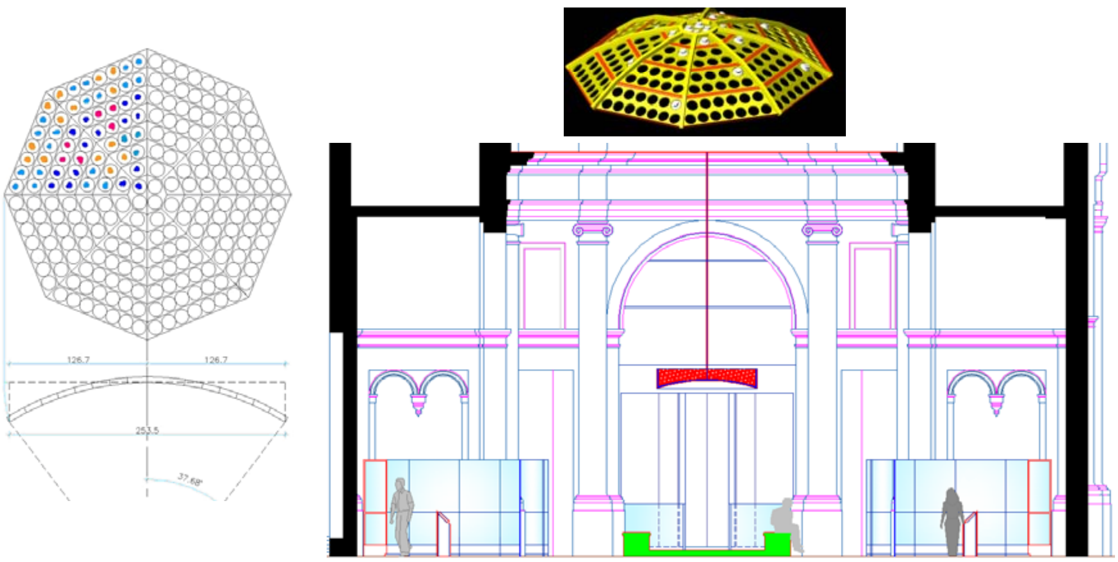

Figure 2. The Sonic Chandelier: structure and placement in the main hall

The geometry of the chandelier and the choice of the speakers are the consequence of an accurate preliminary study on WFS theory and simulations of the acoustic field that involve the measured directivity of the speakers and the processing algorithms.
The first experiments were made on a linear prototype, optimal for the study of the algorithms being developed, limiting the movements of the virtual sources to a bi-dimensional space.
The core of the system is a Linux machine that provides playback and multi-channel processing; the soundcard is an RME MADI, driving 64 digital channels, connected with 8 DA converters (Behringer ADA 8000) that pilot 8 multi-channel amplifiers (QSC CX 168).
The processing is based on the introduction of variable gains and delays in the audio channels: this gives the possibility of synthetising the field of a virtual source placed almost everywhere inside a well-defined conical volume above the listeners. This processing is implemented in real time by software designed for this purpose on the Linux platform, cascaded with BruteFir convolution software [1]; a MIDI controller provides control for dynamic spatialization (several sources in movement).
Only one listener or a small group of them can hear the spatialization in an optimal way, but this has a positive repercussion on the whole expositive area: all the sound is confined at the centre of the room, with a benefit for the other sound messages present in the peripheral area.
One of the most difficult aspects was this lack of physical separation between the areas: the church is quite reverberant (~2.3s at 1 kHz), there is an audio message in the centre and six other different audio messages in the six lateral expositive niches.

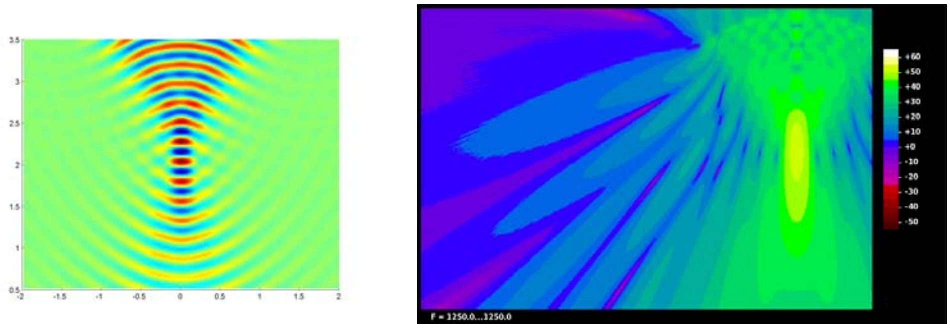

Figure 3. The Sonic Chandelier: simulations of the directivity

Several simulations with Ramsete software [2] were made finding the optimal solutions, compromises between the aesthetic design (a lot of transparency and open spaces) and the acoustical requirements. A wooden platform with absorbing material inside forces the listener below the chandelier and prevent the sound' s reflections on the floor.
A famous composer, m° Martino Traversa, made the musical composition and spatialization for the chandelier, a welcome message for all the visitors.

3. NICHES FOR THE EXPOSURE

The best ancient radios and gramophones, jewels of the museum, are placed in the six niches around the central area. Inside every niche the visitor, through a touch-screen computer (Figure 4) can choose and play recordings of the radio's sound. To reduce the propagation of sound from the niche, two small arrays of speakers are placed behind the listener, near the entrance. The sound is focused in a small area close to the touch-screen, using a QSC Basis and 2 4-channels QSC Amplifiers for steering the sound beams. Hidden at the basement of the niches there is absorbing material coupled with carpet on the ground to reduce the sound level end the reverb.

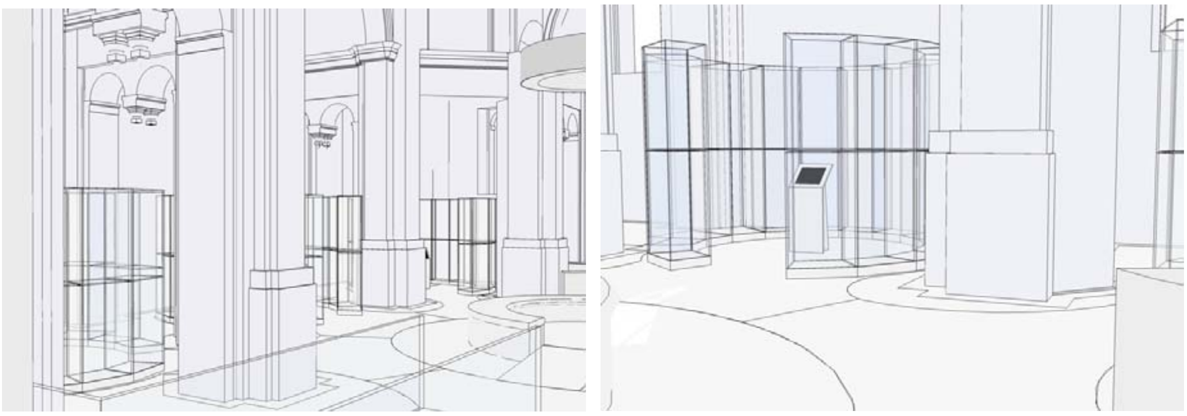

Figure 4. The niches for the exposition

4. HIGH ORDER AMBISONICS AND STEREODIPOLE ROOM

In the big room near the main hall of the church there is a small room (~50 m^3) in which two advanced audio systems are employed: Stereodipole and Ambisonics. The presence of these two different ways of recreating surround permits to the visitor a comparison and a judgement on their realistic performances. This room will be also used for listening tests on sound perception and acoustic of concert halls, theatres and rooms.

The particular listening conditions requested an accurate study of the acoustical treatment with the aim of containing the reverb time, of preventing undesired resonances, of insulating the listener from the external noise.

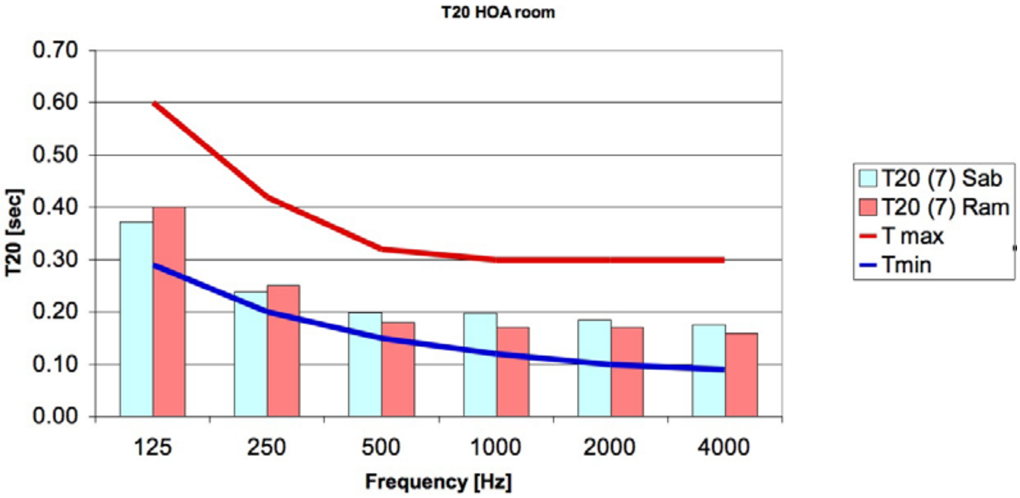

Figure 5. The HOA room: optimal reverb time.

The room is made of modular panels composed by wooden structures and polyester fiber, all covered by dark burlap. The treatment, simulated with the software Ramsete, permits a Reverb Time of 0.40 seconds on the band of 125 Hz, as shown in the picture above (Figure 5), and a lower value for the upper bands.

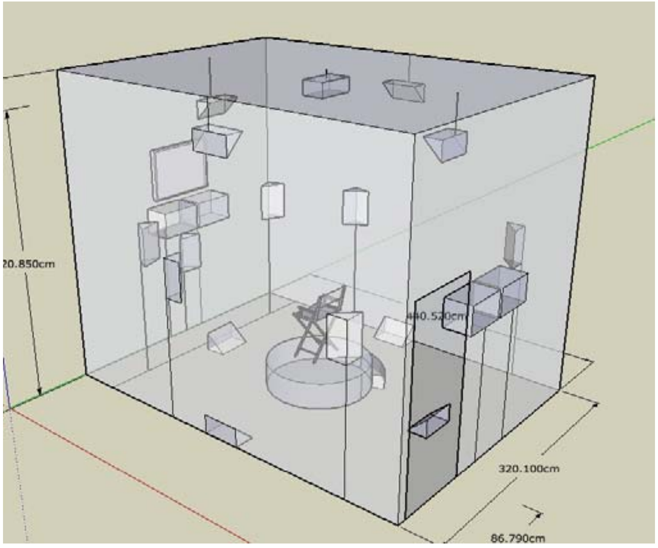

Figure 6. The HOA room: layout of Ambisonic and Stereodipole speakers

4.1 The Ambisonics system

The system is based on the decomposition of the sound field in spherical harmonics [3], a theory developed by Gerzon since the ‘70s, and gives the capability, starting from a well defined spatial sampling, of reconstructing the acoustic field through an array of loudspeakers.

This room has a 3-D array made of 16 speakers (QSC AD 52S) placed as in the Figure 6 and a 30” LCD monitor for the interaction listener-system. The array is driven by a Linux workstation, an RME MADI sound card (24 bit, 96 KHz), and 2 RME DA converters that pilot 2 QSC 8-channel amplifiers. All the instrumentation is mounted in a rack out of the room to prevent the disturbance of its noise inside the room.

The number of speakers is sufficient for a good 2nd order Ambisonic reproduction: is made of a 7 speakers planar ring, 4 speakers on the ceiling and 4 speakers on the ground, with the presence of another one exactly above the listening point: this last one has the aim of a perfect reproduction of the sounds coming from above.

The playback of the tracks is made by Ardour multi-track software, connected through Jack with the Ambisonic Decoder [4]. This decoder, developed by F. Adriaensen, gives the capability of a different decoding of medium-bass and medium-high frequencies, the use of near-field filters, gains and delays if the layout is not regular (Figure 7). Before the installation of the system some simulations were made with the aim of finding the best coefficients for a 1st and 2nd Ambisonic order decoder, optimizing the velocity vector for the bass frequencies and the energy vector for the high frequencies.

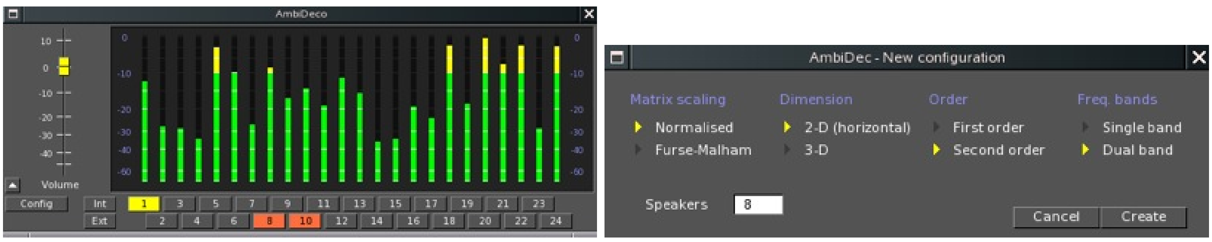

Figure 7. The Ambisonic Decoder

A first prototype of this system was implemented in the laboratory of Casa della Musica (Parma) with the aim of testing the decoder, the right placement, the tracks.

4.2 The Stereodipole system

Aim of the stereodipole [5] is to recreate from binaural recordings the right sound signal at the ears of the listener, the same sound pressure that it would be at the real sound event. Such system, in his basic layout, uses a couple of speakers, each piloted by a processed version of the original binaural recording, using the "cross-talk cancellation" technique.
Inside this room 2 QSC AD82S speakers are placed in front of the listening point and 2 of the same type below the listener, placed with an angle of 10°; a subwoofer helps the system at the low frequencies. All the inverse filters for the linearization of the speakers (Kirkeby technique) and the filters for the cross-talk cancellation were implemented and they are convolved in real time with the binaural recordings.

5. WAVE FIELD SYNTHESIS ROOM

This room (96 m^3) will be ready at the end of September: it is placed between the HOA Room and the main hall (Figure 8), it will host 30 listeners and will be equipped with a planar WFS system. The reconstruction of the acoustic field will be made in 2D through a continuous planar ring of 200 speakers all around the listeners, driven by a 2 Linux machines, each featuring a couple of RME MADI sound cards, Behringer DA converters and QSC multi-channel amplifiers.

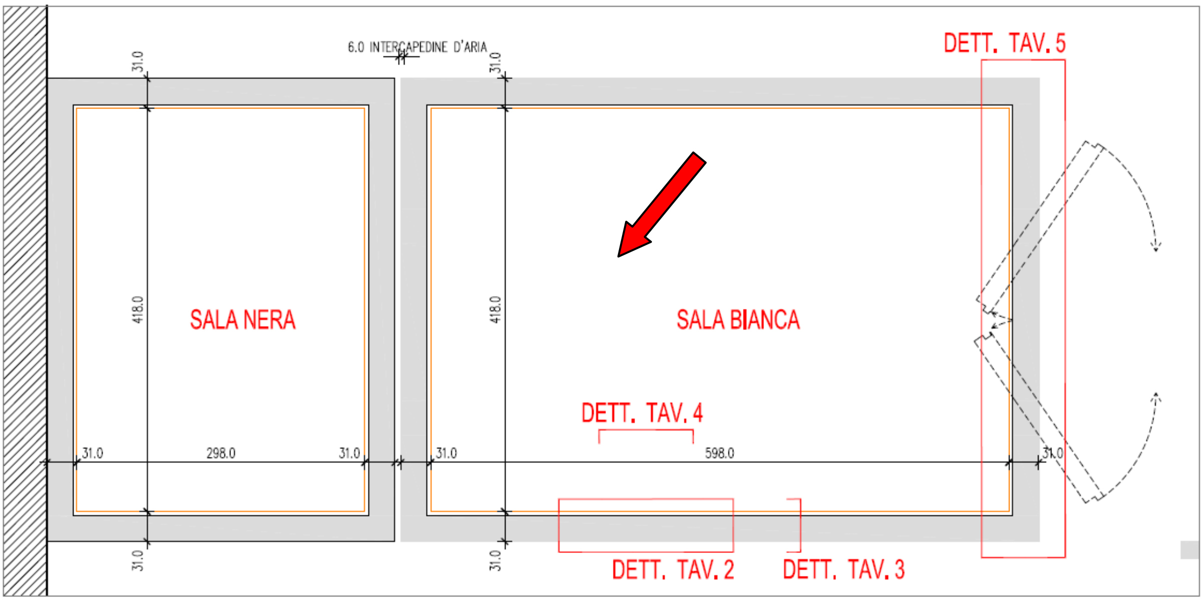

Figure 8. The HOA room (sala Nera) and the WFS room (sala Bianca)

Modular, multi-layered panels will be employed the structure of the room: each panel will be also the acoustic chamber for the speakers; it will have a high absorption coefficient for a comfortable listening and a good insulation from the external noise. On the floor a thick carpet will be placed, and the acoustic will be variable through curved panels (reflective on one side, absorbent on the other) placed on the ceiling and in the lowest part of the lateral walls.
Some details on the structure of the walls and the way in which the rotating panels can be moved are not yet defined at the time of writing; these details will be finalized during summer 2007, after the main exposition in the museum will be opened.
Fig. 9 shows some structural details.

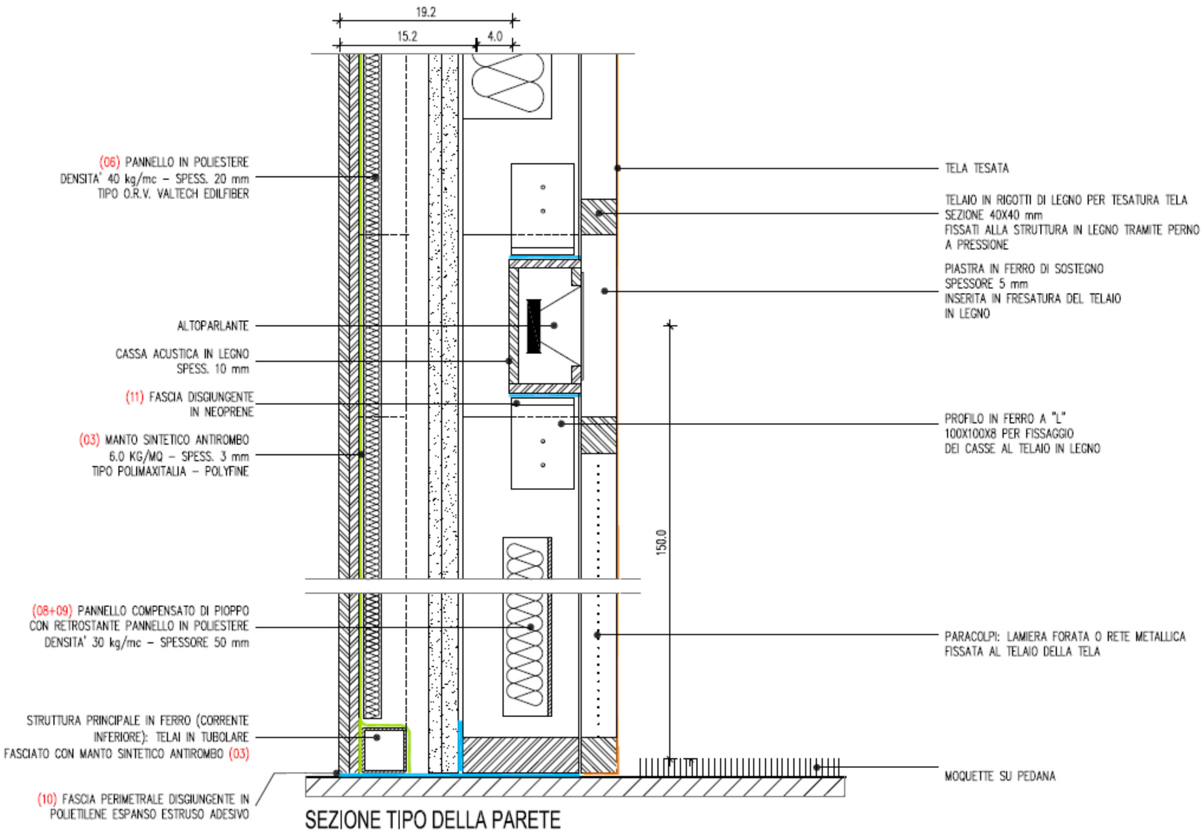

Fig. 9 – structural details of the wall of the WFS room with embedded loudspeakers

The main goal for a WFS room is to be able to perform live modern music compositions or to play back recordings of them. It is expected to be able to convert for WFS playback many different types of "spatial sound", starting from "standard" 5.1 surround, going through 2D Ambisonics, and allowing for maximum effect when employing WFS-optimized compositions. The idea is to create an international network of facilities and composers, so that each of them is allowed to present his artistic work in different countries, preserving as much as possible the spatial information, incorporated in this new type of "spatial music". This network should include research labs already equipped with WFS rooms, such as IRCAM in Paris or the Technical University of Delft (where WFS was invented), but also labs previously more involved with other spatial sound methods, such as the university of York (where large and small Ambisonics rooms are in use by years), the TU of Berlin, etc.
Of course, each of these facilities is different, and it will be necessary to develop a new generation of software tools, capable of "transcoding" audio information for all these different systems.
The starting point for the WFS listening room in the Museum of Reproduced Sound is the open-source WFS package Wonder [5], which allows for realtime movement of several sound sources in the plane, as shown in fig. 10.

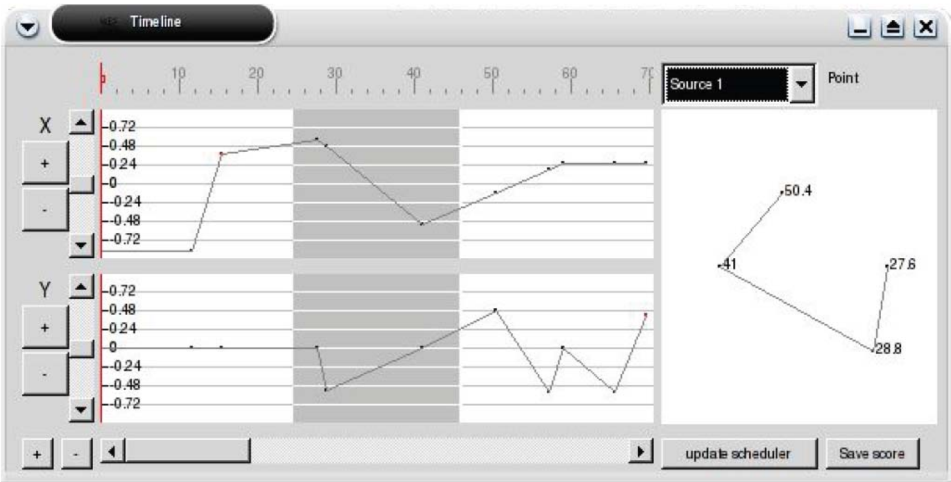

Figure 10. User's interface of Wonder – defining the trajectory of a sound source

6. CONCLUSIONS

The final goal of both the HOA/StereoDipole single-listener room and of the WFS 30-seats room is to capability to synthesize a complete virtual sound field, based either on impulse response measurements made in an existing concert hall, or on the results of computer modelling.

Regarding the latter topic, it is worth mentioning that we are currently upgrading the Ramsete room simulation package. At the moment, this software can produce binaural auralization only, by synthesizing binaural impulse responses.

A new version has been recently introduced (Ramsete 2.5), which provides 1^{st}-order Ambisonics (4-channels) impulse responses. And in the near future, Ramsete will be further extended, with the synthesis of 3^{rd} order Ambisonics impulse responses, and with the automatic creation of setup files for Wonder, enabling a WFS rendering of the simulation results.

This means that the two listening rooms at the Museum of Reproduced Sound will be employed not only for playback of modern "spatial" music, but also for research on the perceptual attributes of spatial sound. In particular, we are mainly interested in understanding what are the spatial attributes providing a pleasant sense of envelopment, and to explore the usage of advanced spatial descriptors and their correlation of human perceptions.

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