THE ORA PROJECT: AUDIO-VISUAL LIVE ELECTRONICS AND THE PIPE ORGAN

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ABSTRACT

This paper presents musical and technological aspects of real-time digital audio processing and visual rendering applied to a grand nineteen-century pipe organ. The organ is "augmented" in both its musical range and visual dimensions, thus increasing its potential for expression. The discussed project was presented to a public audience in the form of concerts. First, a brief project description is given, followed by in-depth discussions of the signal processing strategies and general musical considerations. Digital audio effects allow for the addition of new electronic registers to the organ stops. The "direct" sound is captured inside the organ case close to the pipes in order to provide "dry" audio signals for further processing. The room acoustic strongly affects the pipe organ sound perceived by the listener; hence, to combine the processed sound with the organ sound both room simulation and spatial audio rendering are applied. Consequently, the transformed sound is played back via a multitude of loudspeakers surrounding the audience. Finally, considerations of musical aspects are discussed, comprising reflections on virtuosity and technique in the musical play and how the new possibilities could affect composition practice and the use of the organ in contemporary music.

1. INTRODUCTION

The use of live-electronics and augmented instruments is common practice in contemporary music performance and media art. In general practice, the instrument's direct sound is captured with microphones or other kinds of sound pick-up, processed in real-time, and played back over loudspeakers. Applying audio signal processing and spatial rendering to grand pipe organs in the same manner as with orchestra instruments raises many interesting questions, which will be discussed in this article. Previous pieces using live-electronic processing applied to the pipe organ are described in [1]. The pipe organ timbre depends not only on the instrument itself, but also on the interaction with the room acoustic; the instrument's 'inner sound' significantly differs from the sound perceived by the listeners. It is well known in organ music interpretation and composition that the organist plays with the organ and the corresponding room acoustic response in a unique way. This inner / outer sound dialogue is envisaged from a technical and musical point of view in Section 3.

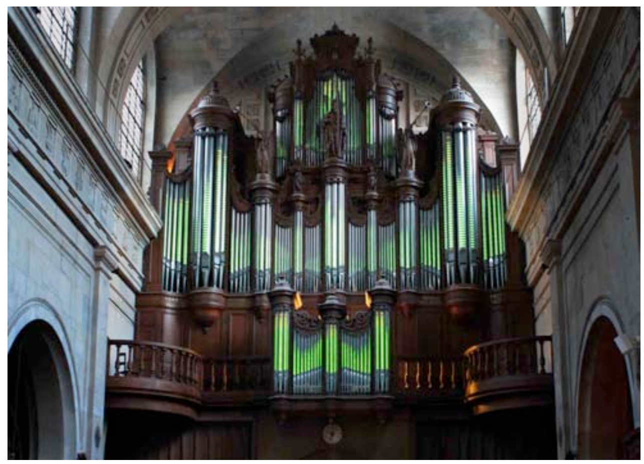

Figure 1. Snapshot of the visual animation during an ORA concert; the instrument's façade is lively animated by the played music.

Another contribution of this project is to extend registration possibilities by mixing the direct acoustic sound of the instrument with virtual registers computed in real-time using digital audio effects on the acoustic pipe sound (Section 4).
New sound possibilities, new registration possibilities, and new spatial sound restitution can be used for the classical repertoire, but call also for new music (section 5).

2. THE ORA PROJECT

The ORA (*fr. Orgue et Réalité Augmentée*) project was realized in the Sainte Elisabeth church in Paris, spring 2008. The primary goal was to immerse the audience in a unique multimodal audio-visual experience. For visualization the spectral content of the played music was

projected as digital VU-meters on the organ's façade pipes (see Figure 1; and [4] for details on visual aspects).
The instrument is a large romantic organ (1853) comprising 39 stops, 42 registers, 3 manual keyboards, and a pedal-board. Its base footprint is about 10x10 m, with three main levels for the four divisions (2322 pipes, 141 visible at the organ façade).

3. INNER/OUTER SOUND: CAPTURE AND SPATIAL AUDIO

3.1. Inner Sound Capture and Audio Setup

To decouple the sound from the influence of the room acoustic, it is captured inside the organ case. The achievable sound quality strongly depends on the number and positions of microphones used. Five omnidirectional microphones were placed in the *Positif* (1), the *Grand Orgue* and *Pédale* (3), and the *Récit* (1). Typically, omnidirectional microphones have a more extended low frequency response and lower distortion than directional microphones. To avoid distortions caused by the very high sound pressure level close to the pipes, microphones with a very high dynamic range have been used. The divisions of the organ case are acoustically well separated, so that the captured sound is well decoupled from neighboring divisions (at least for mid and high frequencies).
The sound captured as described above contains significantly less reverberation, higher low frequency energy, and provides better articulation, higher precision, and clearer transients than the sound outside the organ. As the attacks of the inner sound are very precisely defined, it offers much more variation to the organist for playing with articulation.
The microphone signals are processed in real-time using Pure Data and are re-distributed to 8 Haliaetus Blackbird loudspeakers surrounding the audience. An active Genelec 7071A subwoofer is fed with a low-pass filtered sum of the surround loudspeaker feed signals. In addition, the power spectral density of each microphone is estimated in third-octave bands and each sub-band level is sent to the graphical rendering units via Ethernet (UDP). Figure 3 illustrates the audio setup.

3.2. Spatial Audio Reproduction and Effects

Combining the processed sounds with the organ sounds at the listener's position requires spatial redistribution and additional room simulation. The proposed environment uses third-order Ambisonics for sound field reproduction in the horizontal plane [3] [7]. The inherent free-field assumption of the Ambisonics approach, i.e. the basic assumption of reproducing the sound field in a source free medium, usually limits its use in real situations. Especially in churches, strong early reflections and long reverberation times – necessary for the traditional organ sound – deteriorate the accuracy of the sound field reproduction and degrade subjective localization. The limitation to a finite number of playback channels further reduces the area of accurate sound field reproduction (sweet spot). Applying weighting functions before decoding the Ambisonics signals into loudspeaker feed signals broadens the sweet spot area but also increases the perceived source width. To overcome the problems linked to a real reproduction environment as mentioned above, the audio effect design for extended registration concentrates on principally non-localizable / non-focused sounds and spatial granular synthesis.
The use of multichannel sound field reproduction for spatialization and movement of sound through space adds a new compositional feature to organ music. It allows projecting the organ's "inner" sound into the "outer" space, thus changing its relation to the acoustic environment. Room acoustic and psychoacoustic effects determine the perceived dialogue between the acoustic and electroacoustic sound. For example, as the loudspeakers are closer to the audience than the organ pipes, the processed sound might - due to the shorter acoustic propagation path delay - arrive earlier at the listener than the direct organ sound. This creates the impression that the sound comes from the location of the loudspeaker not from the organ itself (Precedence Effect); the organ sound then is perceived as early reflection or reverberant energy, rather than as the direct sound. Many different spatiotemporal interrelations can be observed in this context, which also depend on the listener's position.

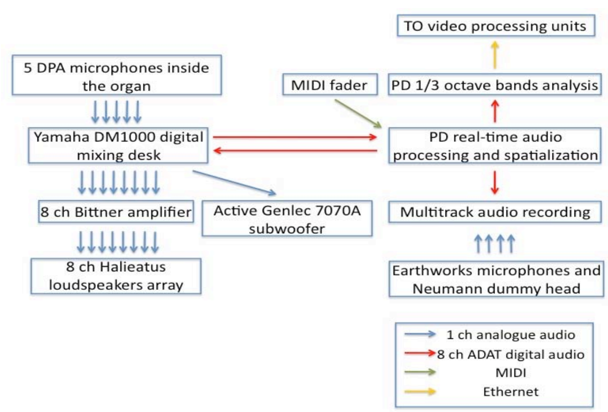

Figure 2. Audio setup

The following spatial effects have been used as a compositional element:

- **Virtual organ divisions**: the sound captured inside the different divisions of the organ case can be relocated in space; for instance, the Récit on top of the organ can be virtually placed behind the audience. The spatialized "inner" sound is reverberated by the room acoustics and can merge, interfere, or dominates the real organ sound.

- **Sound motion**: due to real-time spatial control the "inner" sound of a division can be moved around the audience in a time-varying manner, for instance to mimic a cortege of marching singers.
- **Reverberation effects**: adding directionally encoded early reflections and late reverberation to the "inner" organ sound allows one to virtually enlarge the perceived spaciousness.
- **Spatial granular synthesis**: the "inner" sound is chopped into short sound snippets, which are randomly redistributed in space.

4. ACOUSTIC MIXTURES AND ELECTRONIC EFFECTS

From the very beginning, the organ sound is based on the combination of pipe ranks or registers. Augmenting the pipe organ by means of digital audio signal processing – i.e. by adding "electronic registers" - pushes the boundary of traditional organ sounds. Various effects can be added, which strongly depend on the acoustics of the different pipes. Acoustic documentation of this instrument is reported in [2].

4.1. Some Acoustic Features of Pipe Families

Reeds are characterized by a spectrum that is very rich in harmonics and a relatively loud tone, but are somehow unbalanced in their loudness profile; the bass is normally much louder than the high notes. In general transients are short (short attack time) and not very prominent. Reeds saturate the spectrum and are therefore often used for powerful, strong acoustic effects in traditional organ music. Some ranks, like the *Voix Humaine*, are built with short pipes yielding spectral resonances similar to the vocal formants of the human voice, close to the vowel /a/.

Due to the rich spectrum of reed pipes, audio effects derived from subtractive synthesis are best applicable; by adding further harmonics the resulting dense spectrum creates noise like sounds.

In contrast to reed pipes, flue pipe sounds are mainly limited to a few harmonics for some stopped ranks (*e.g.* the *Bourdon*). The transient sound is markedly different from the sustained sound, allowing for a large variety in articulation. Historically, flue pipes were combined to create sounds in an additive synthesis like manner: the so-called "mixture" or "mutation" registers. Flue pipes are well suited to additive synthesis resulting in harmonically rich sounds.

4.2. Additive and Subtractive Digital Audio Effects

In addition to spatial rendering two effect categories have been applied: "additive" effects that enrich the original sound, and "subtractive" effects that spectrally shape the original sound.

Within this project real-time harmonizers and ring modulators have been applied to the pipe sound captured inside the organ case [8] [9]. Harmonizing relates to mixing a sound with several pitch-shifted versions of itself. In practice the microphones capture the global sound of each organ division, rather than the sound of individual pipes. Applying a harmonizer to this polyphonic input signal produces many inharmonic partials, which add to the original spectrum of the signal, creating a dense and inharmonic sound. Various shifting ratios are used in order to produce different degrees of inharmonicity.

Reed pipe sounds have a dense frequency spectrum, which makes additive synthesis algorithms non-applicable. On the contrary, subtractive synthesis techniques allow to spectrally shaping the rich pipe organ sound. The Karplus-Strong synthesis technique provides a computational efficient and simple approach to subtractive synthesis [5]. The algorithm consists of a delay line and low-pass filter arranged in a closed loop simulating the reflected waves of a string. Using variable delays allows dynamic control of the resonance effects.

The effect of the application of the Karplus-Strong algorithm to *e.g.* reed pipes is variable spectral shaping. When playing in a fast tempo, the resulting sound has a sparkling quality, with fast formant motions like a human voice.

5. SOME MUSICAL CONSEQUENCES

It is difficult to apply audio effects to classical music repertoire without destroying its subtle musical content. Then only spatial audio and reverberation effects were used in conjunction with classical music.

The first type of effects is sound relocation in the church, i.e. the captured inner sound captured is played-back from different places in the church. The second type of effects is sound motion, which typically works very well with music accompanied by solo voices: like a singer moving in the church. A stronger effect is given by the slow extension and retraction of the sound of a division in the acoustic space, like a tide rising and falling. A third type of effects is the virtual acoustical enlargement of the room augmentation by adding artificial reverberation and early reflections. The relatively small church was acoustically transformed into a grand cathedral. The use of digital effects in classical music is somewhat paradoxical, as very often these effects are considered as euphonic as long as they do not sound "electronic", and therefore remain primarily unnoticeable.

A cycle of pieces in 12 parts was especially composed for this project. The main argument is to play with inner space and outer space, capturing inside and playing outside the instrument. This argument is also a metaphor for the music itself, based on a short text by Dorothée Quoniam: "les 12 degrés du silence" (" the 12 degrees of silence"). Quoniam, a 19th century Carmelite, explained to a young sister the teachings of her inner voice. Then the cycle is about speech, silence, inner and outer voices. It is played in alternation with classical repertoire music. This piece makes use of the unusual sound possibilities offered by the system.

The technical system used gives a successful fusion of direct sound and live electronics. Depending on the balance between the direct sound and processed sound, the result can have an "electronic" quality or an "acoustic" quality, even with electronic modifications that are not perceived as such.

Different digital audio effects give different results depending on the type of pipes they are used with. "Additive" effects continue the tradition of "mutation" ranks in historical instruments; electronics allow for dynamic inharmonic ranks addition/suppression.

The inharmonicity provided by the harmonizer and reverberations transforms the pipe sounds in percussion-like sounds (see Figure 3). The harmonizer associated to all the foundation stops in the bass and medium bass register gives a very inharmonic sound, like a plate of metal played with a bow.

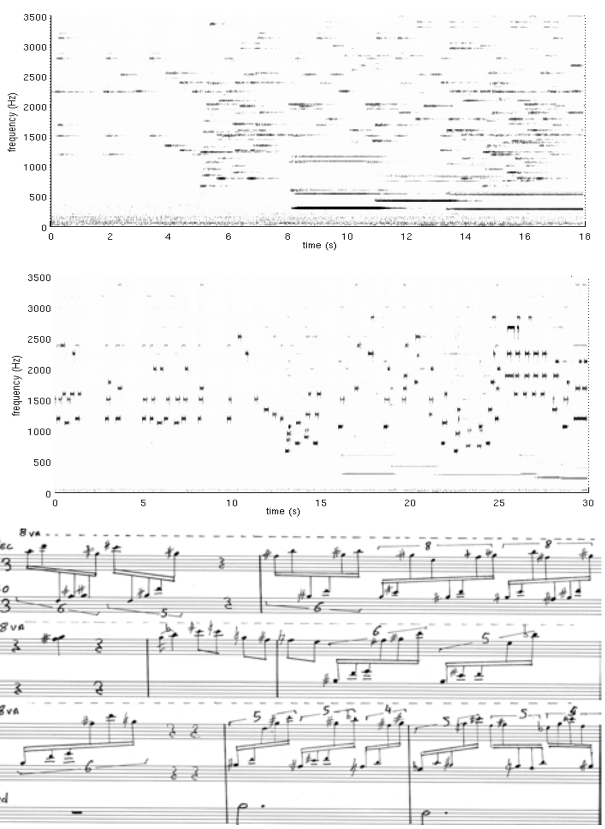

Figure 3. Effect of the harmonizer: Spectrogram of the outer sound in the church, with visible inharmonic partials. Middle: spectrogram of the inner sound in the Récit division, and bottom, corresponding score (played on 4' and 2' flutes, corresponding to 0-20'').

"Spectrum shaping" effects give formant like qualities to reed pipes (pipes with rich spectra). This would correspond to dynamic modifications of the pipe shape and dimension, and effect which is not possible with acoustic pipes. The Karplus-strong effect is used in conjunction with reeds. The variable filtering effect of the algorithm associated to the rich reed spectra gives a vocalic quality of the organ sound. The instrument speaks like a giant voice, but in an unknown and unintelligible language.

Spatial audio effects are an integral part of the instrument augmentation, and contribute much to the electronic/acoustic perceptual fusion. For instance, when impulse-like chords or clusters are exciting the virtual acoustics of a very large room, the short articulation silence between impulses is carefully controlled, in order to play with the real and virtual room as an acoustics filter.

In summary, this project demonstrated that live electronics and the pipe organ can extent the instrument's musical possibilities and repertoire, while maintaining its historical character. It is then possible to mix classical and contemporary music harmoniously. The augmented instrument is offering performers and composers new expression means.

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