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Contents

Musical Informatics: Expression and Performance Analysis II

Musical Systems and Computer Assisted Composition

Music Analysis and Cognition

Music Archives

Restoration of Audio Documents I (Special Session)

Restoration of Audio Documents II (Special Session)

Poster Session I

Poster Session II

Demos

Musical Compositions

Listening Session I

Listening Session II

Listening Session III

Listening Session IV

SOUND RECOVERY OF COMPUTER MUSIC WORKS PRODUCED WITH LOW SAMPLING RATES: THE CASE OF *Traiettoria*[1]

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Abstract

This text will delve into the main problems we had to face while recovering the electronics of Traiettoria *by Marco Stroppa, a piece for piano and computer-generated sounds produced at the Centro di Sonologia Computazionale of the University of Padua between 1982 and 1984. This work, synthesized at a sampling rate of 15 kHz, has therefore an audio range limited to 7.5 kHz. In addition, since in 1988 it was analogically recorded onto a DAT tape, the new digital master contained also some defects due to the conversion. We will describe the various phases of the process of audio recovery and will focus particularly on the algorithm devised to restore brightness to the original signal by generating synthetic events that are coherent with it in the frequency range superior to 7.5 kHz. This algorithm is based on two steps: the analysis of the input signal and the synthesis of the high-frequency region according to parameters deduced from the analytical data. The newly generated region is then added to the original signal.*

1 Introduction

It might seem inappropriate to apply the issue of audio recovery to musical works as recent as those using computer-generated sounds [1], but many pieces produced in the 70's and early 80's occasionally had to pay for the limitations of the technology at that time. Quite frequently, in fact, they were synthesized at sampling rates much inferior to 44.1 kHz, which has then become the musical standard since the introduction of compact discs. In such cases, the electronic sounds have a limited frequency range and must be recovered by giving them more brightness.

As far as the support chosen for the master recording is concerned, some works were digitally recorded and therefore should not contain more defects, let alone the ones due to the low sampling rate; others, however, were recorded onto an analog tape or had to be converted from a digital to an analog format one or more times before being digitally recorded. In both cases their audio recovery is mandatory because of analog tape hiss and other troubles due to a mediocre digital-to-analog and analog-to-digital conversion.

The tape of the piece discussed here contained both defects and is therefore emblematic of the issue of sound recovery of many computer-music pieces composed at that time. *Traiettoria* is a 45-minutes work for piano and electronic sounds generated by computer composed by Marco Stroppa. It consists of three movements (*Traiettoria...deviata*, *Dialoghi*, and *Contrasti*) and was produced at the Centro di Sonologia Computazionale (CSC) between 1982 and 1984 [2, 3]. The performance of *Traiettoria* requires the diffusion of the electronic sounds recorded on a compact disc via a multi-channel amplification system, made of several speakers placed on the stage and around the audience and of one speaker located underneath the piano and facing upwards towards the sound board.

In order to maximize musical interaction and sound quality, the electronic sounds were recorded at a high dynamic level even in the soft sections of the piece. It is the interpreter in charge of the sound diffusion who has the task of finding the right levels in tune with the pianist and of shaping the sounds in space as a function of the acoustics of the hall and of the characteristics of the sound diffusion system.

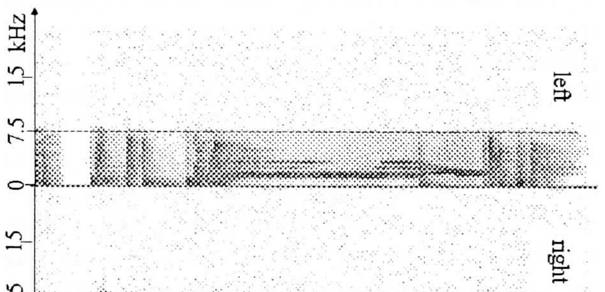

Fig. 1. Beginning of *Contrasti*

Although *Traiettoria* is a fairly recent piece, the electronic sounds require being recovered for the following reasons. First the system for the digital-to-

[1] This work has been carried out with the financial support of the CNR - Progetto finalizzato Beni Culturali

analog conversion used at the CSC in the early '80's allowed a maximum sampling rate of 15 kHz, thus limiting the audio range to 7.5 kHz (fig. 1).

Second, when in 1988 the composer decided to make a digital master of the piece the computers of the CSC did not have yet a digital output. It was therefore necessary to record it on a DAT tape analogically. As a consequence, the recovery of the electronic sounds requires two sorts of operations: the reduction of the noise due to the double conversion and the generation of the missing frequency region starting at 7.5 kHz.

This procedure is greatly different from the one employed for the recovery of analog works that have such defects as impulsive noises (clicks due to scratches of vinyl records or magnetization problems of tapes), hiss and audio distortions [4]. In our case, the background noise was limited to imperfections of the D/A and A/D conversion, which have appeared only since the adoption of digital technology. The problem of generating the missing high-frequency region is also new and is a direct consequence of digital sound (low sampling rate). However, it could also be applied to analog materials recorded with a limited spectral range.

2 Reduction of the defects of the conversion

The system used at the CSC in the '80s to transfer the electronic sounds of *Traiettoria* on a DAT cassette was not a commercial product, but a 16-bit prototype built with discrete elements by the Department of Electronic Engineering of the University of Padua [5]. The DAT was one of the first semi-professional portable machines. The transfer thus introduced some noise, albeit quite moderate, which was not present in the original sounds. The noise was more perceptible in low sounds with a limited spectrum, but was not very serious. The software plug-in DINR from Digidesign [6] (version 1.01), running under Sound Designer II (version 2.6) on a Power Macintosh computer could efficiently reduce it using the Broadband Noise Reduction (BNR) module. BNR uses a proprietary technique (called Dynamic Audio Signal Modeling) to analyze a segment of noise in the audio file and to build an internal dynamic spectral model of what the noise and the desired audio "sound" like. It then attempts to "pull apart" the two models, separating the noise from the desired audio. Fig. 2 shows the spectrum of the conversion noise of *Traiettoria*. The bump in the low register corresponds to the pitch of a low B flat. Since the noise was produced by the converters, it was only present with some sound and not during silent sections. It was therefore impossible to isolate a segment of noise alone in any sound file. The line connected by squares is the actual spectral model: it was obtained by creating a model of an area containing only noise (above 500 Hz approximately) and expanding it to the lower region of the spectrum.

To obtain a sufficiently clean signal without provoking spectral artifacts a total amount of noise reduction of 10.17 dB was considered satisfactory (fig. 2).

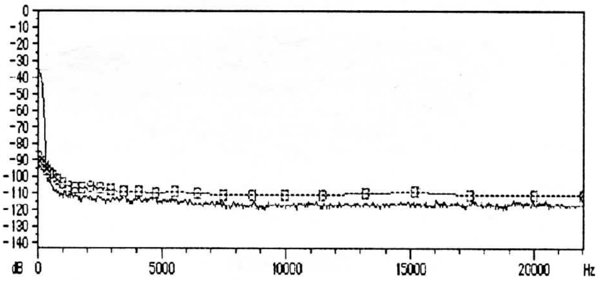

Fig. 2 Spectral Graph Display of the conversion noise of *Traiettoria.*

3 Generation of the missing high-frequency signal

Traditionally, the audio recovery of old analog materials requires the reduction of various noises masking some areas of the sound spectrum. Here, however, the process is totally different: it is not a question of making "audible" previously masked spectral areas, but of generating a high-frequency signal that is missing in the original, although it has to be coherent with it.

In order to find a model of high-frequency signals to be used as a reference, we analyzed the spectral energy above 7.5 kHz of some instrumental sounds: piano, string quartet, large orchestra and percussion ensemble. After listening to these filtered sounds, we observed how varied and differentiated both their energy and their timbral characteristics were: piano sounds do not contain a lot of energy in this region, while the string quartet is much richer and sensitive to changes in frequency, especially to glissandi. The orchestra shows a homogeneous distribution of energy over the whole area. The percussion ensemble, finally, is the richest and the most diversified, probably because several instruments generate a spectrum that is mainly situated in this area, while other instruments also cover it in many different ways.

From the standpoint of timbral quality, we identified two main morphologies: the high-frequency range consists either of clusters of sinusoidal sounds that are sometimes slightly modulated by an amplitude jitter (random variations), or of narrow bands of white noise.

An aural test led us to choose the first morphology for *Traiettoria*, since it seemed more coherent with the type of synthetic sounds used in the piece from both a perceptual and a theoretical perspective (all the sounds were generated using additive synthesis or frequency modulation).

The next problem was then how to generate these clusters of sinusoids. We started from the psychoacoustical consideration that only notes with a frequency below 4-5 kHz are musically meaningful (the last note that an orchestra can play is about 4.1 kHz). We have thus chosen to analyze the energy of the spectral region between 4 and 7.5 kHz (middle-high range) and to project it in the region between 7.5 and 22.05 kHz (very-high range, taking the standard sampling rate of 44.1 kHz as a reference). We divided the two spectral regions into their critical bands [7] and controlled the energy of the very-high one with data coming from the analysis of the middle-high region.

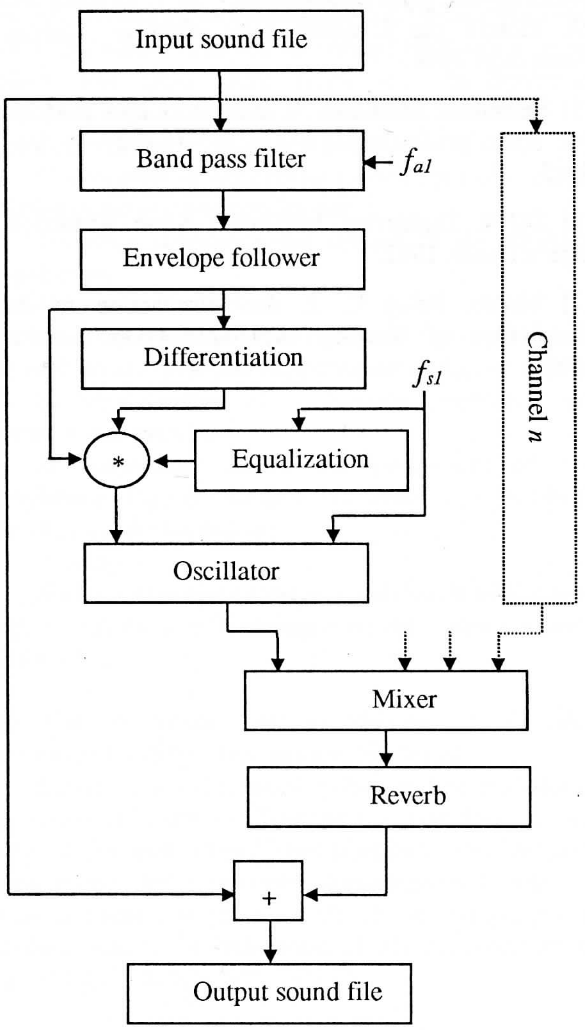

Fig. 3: Flowchart of one channel of the analysis-synthesis algorithm

For each band, we extracted the amplitude envelope and its derivative. The latter proved to be particularly useful to detect fast transients, which, as is well known, contain a lot of energy in the high-frequency range. During the experimental phase of our work, in fact, we observed that synthesizing the high-frequency range with data coming just from the amplitude envelope wasn't very successful. Too much energy was present and this was inconsistent with both our analytical data and with our perceptual simulations. However, when multiplying the amplitude envelope with its derivative we obtained optimal results.

Conversely, using the derivative alone yielded less balanced temporal contours, since they were dependent only from the rate of change of the amplitude and did not take into account its absolute value. This led to an excessive strengthening of the high-frequency range for rapid transients with a soft dynamic level.

Our analytical data also showed that it was essential to slightly vary the frequency of the sinusoidal clusters. A random variation within the critical band proved to be enough. The change of frequency was performed when the amplitude was zero. In this way, potentially harmful and perceptible discontinuities were eliminated. Finally, a reverb of 2.5 sec was applied exclusively to the newly generated high-frequency signal in order to give it a more homogeneous timbre. Both these additions were judged adequate and sufficient when tested aurally. Fig. 3 shows the flowchart of one channel of the analysis-synthesis algorithm used to generate the high-frequency signal.

The algorithm was very effective in recovering the missing high-frequency region of *Traiettoria.* It performed well with all the sound morphologies of the piece, such as percussive sounds, granular glissandi, continuous layers, and the like. Fig. 4 illustrates the sonogram of the beginning of *Contrasti* with the newly generated high-frequency region.

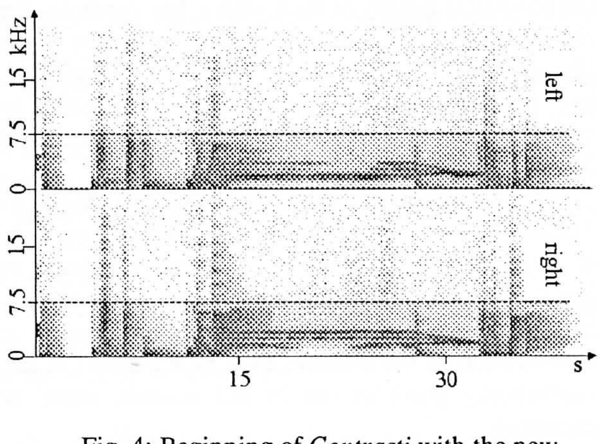

Fig. 4: Beginning of *Contrasti* with the new high-frequency region

However, every process of audio recovery has a component of craftsmanship that cannot be totally automated, especially when the sound files are as long and varied as in *Traiettoria.* The electronic sounds last more than half-an-hour and are divided into 8 sections whose duration is between 3' and 7'. In order to obtain a more musical result, we finely tuned the control parameters of the algorithm for each section. Sometimes, the high-frequency region of one section was generated more than once with slightly dissimilar control parameters and recorded onto separated sound files. We then superposed all the available sound files to the original signal, but we always kept them in the different channels of a multi-tracks direct-to-disk system (ProTools from Digidesign, version 4.1). In this way, the intensity and the choice of one high-frequency file or another was made heuristically while listening in order to obtain the most convincing musical solution.

4 Conclusions

Although the algorithm described above was conceived for audio recovery, it might also be used as a compositional tool. When generating electronic sounds, the musically pertinent frequencies, that is the frequencies to which a given compositional thought can be applied and be perceived (provided that the composer has an approach based on musical pitches), are limited to the range of the orchestral instruments. Psychoacoustic research shows that the frequencies above this range are not perceived as pitches [7]. As a consequence, applying the same compositional process to so high frequencies often create problems of energetic balance (the highs tend to be too loud and to last too long), because what is good for musical pitches might not work as well for high-frequency spectra. On the other hand, restricting the maximum frequency of a composition to the beginning of the high-frequency region will probably produce an overall sonic result lacking brightness. The algorithm described above might therefore be useful to improve the acoustical quality of such works. For example, the compositional process might determine the frequencies of the synthetic sounds up to a region of, say, 6÷8 kHz and then recur to this algorithm to enrich the spectrum according to psychoacoustical and not only compositional rules.

We also imagine that the algorithm used in *Traiettoria* might also work in other contexts as well, or could be used to recover historical recordings in which the frequency range is reduced for various reasons: defects during the recording phase or deterioration of the medium used as a support of the magnetizing particles (as in old records, tapes or cassettes).

It is obvious that our cognitive system is much more exacting when dealing with acoustical instruments, since it already possesses a model of how they behave and sound like in the real world. The re-creation of the missing regions will presumably require that we also take into account phase information during the analysis step, that we extend our algorithm so as to include these data and that we find a way to project them onto the missing areas.

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