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Amplitude Modification Algorithms within the Framework of Physical Modeling and of Haptic Gestural Interaction

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ABSTRACT

Every underlying technique which has been used for the realization of audio effects since the beginning of electronic and computer music, introduced different types of sound modifications and proposed new ways of control. The advent of digital signal processing has stimulated the audio processing researchers to a great extent thus a variety of algorithms were designed to provide novel sound modifications. On the other hand, physical modeling and digital simulation formalisms have been principally used for the merely imitation and emulation of older sound processing systems. The aim of this article is to propose three physical models conceived to offer sound modifications which mainly alter the amplitude of audio signals. The originality of this case is not the resulted audio modifications but their transposition in the framework of physical modeling and digital simulation, which outlines an alternative control procedure.

1. INTRODUCTION

Physical modeling, even if it is the most active field in digital sound synthesis the last twenty years, has rarely been proposed as method for the design and the conception of new digital audio effects (DAFx) [1]. So far, it has been used mainly to emulate analogue audio signal processing systems [2][3] or to simulate hall reverberation [4][5].

However, in the past, we have proposed a novel approach to the design of DAFx with the aim to investigate the possibilities of physical modeling to provide more “plausible” sound modifications and alternative control procedures [6][7]. Briefly our method is based on the numerical simulation of vibrating physical objects: at first the input digital audio signal feeds a properly designed virtual viscoelastic system for the purposes of the desired effect; then a set of mechanical manipulations is taking place which consequently modifies dynamically the input sound. Consequently this procedure offers a purely “materialistic” nature in the sound modification. It is the “matter” which is manipulated after all and not the signal. According to the classification proposed in [6], this approach follows the *Propagation Medium Processing* paradigm.

Throughout this research, following our concept we have developed three different CORDIS ANIMA (CA) physical models dedicated to the amplitude modification of audio signals [8]: the *Bend Amplitude Modification Model*, the *Mute Amplitude Modification Model* and the *Pluck Amplitude Modification Model.* The audio effects achieved are similar to amplitude modulation, to distortion and to gain control. Nevertheless they can not be merely classified in these categories as they provide additionally several sonic characteristics not found when designed with digital signal processing techniques. Further more, these models offer a control based on the “Physical Instrumental Interaction” [9].

In the next section, we will present briefly our framework and the physical modelling formalism applied for the proposed DAFx. At that point the three models will be demonstrated. A hybrid diagram will be adopted for the representation of the algorithms: CA networks combined with signal processing block diagrams [10].

2. THE FRAMEWORK AND THE FORMALISM

In this essay, the proposed audio effects are actually computer models of physical objects. Moreover, several gesture models complete the “alphabet” from which the modification algorithms are designed. Generally, our toolbox contains a set of elementary virtual mechanical components –the CA modules (figure 1) - and exceptionally simple digital signal processing building blocks such as adders, multipliers and unit delays.

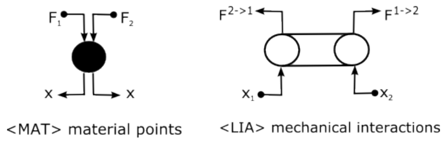

Figure 1 CA two basic modules

Each DAFx model is represented by a plane topological network whose nodes are the punctual matter elements <MAT> and links are the physical interaction elements <LIA> according to the CA formalism. The simulation space used is limited to one dimension. Forces and displacements are projected on a single axis, perpendicular to the network plane. In figures 2-4 we depict the CA basic elements used in the proposed DAFx by their block diagrams.

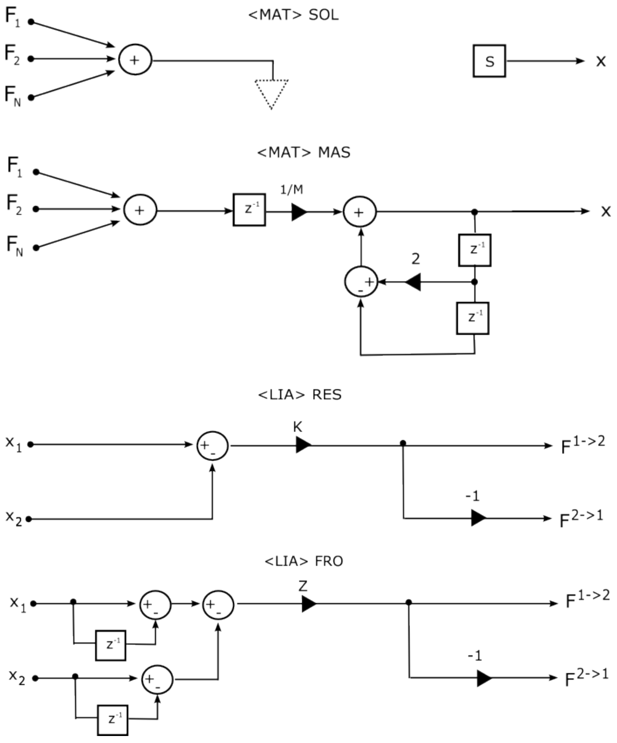

Figure 2 CA linear <MAT > and <LIA> modules and their block diagrams

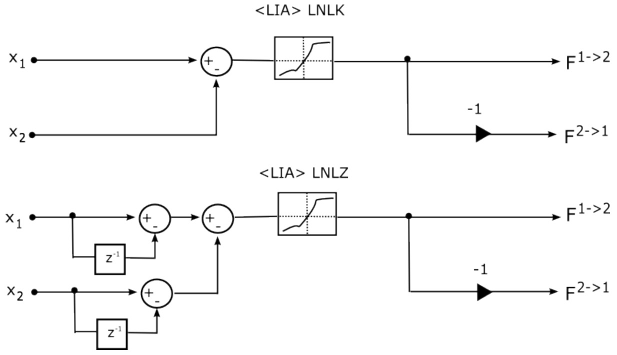

Figure 3 CA nonlinear <LIA> modules and their block diagrams

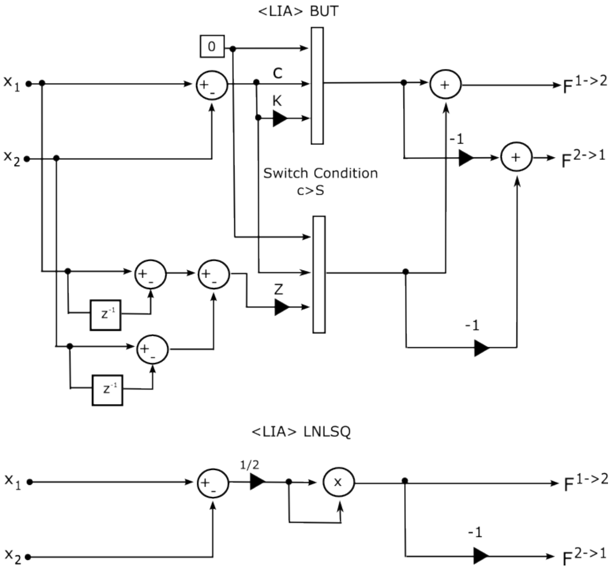

Figure 4 Other CA nonlinear <LIA> modules and their block diagrams

The initial concept behind our models is to establish a physical interaction between the user-musician and the audio effect unit which has virtual material substance. This is feasible of course only by the use of suitable ergotic interfaces or by gesture models. Interestingly in this type of control no mapping layer exists between gesture and sound since no representation is involved in this situation, but only physical processes.

3. AMPLITUDE MODIFICATION MODELS

The three proposed models were designed to allow real time multi-sensorial simulation and interaction: they shall be seen, touched and heard. Their control with force feedback haptic interfaces such as the TGR was our prime interest [12][13]. Additionally, the goal was to maintain a minimum complexity while preserving the "physicality" of the system in all the modeling levels. Hence the CA formalism was preferred because it provides all the essential information required for the internal physical structure of the modeled system.

So far, all models were designed and simulated in differ time using technical computational languages such as matlab & Simulink. Several other simple models where used to simulate the physical mechanical gestures used to control then as well as interact with them. Their design has been based on previous research activities and carried out by GENESIS modeler [14][15].

3.1. The Bend Amplitude Modification Model

The first model may be considered as a physical implementation or interpretation of an amplitude modulation / ring modulation process [1]. The algorithm contains two basic blocks: a second order mechanical oscillator (the modulator which is a low frequency signal in most typical applications -LFO) and a special designed nonlinear elastic link or spring (deviation of the linear Hook law) which may be considered as a physical realization of the multiplication operator. Both the input sound file and the oscillator feed the two sides of the nonlinear link with their positions. The input sound "drives" this link with a low amplitude signal and the oscillator offers approximately a high amplitude "bias" value which changes slowly and controls the functional point of the interaction. The calculated force from this interaction is the modulated output of the audio effect.

In the figure 5 the schematic diagram of the algorithm is depicted. A high pass filter has been used to cut all the low-frequency non-audible components of the output signal. This filter must be very selective hence a high-order Butterworth has been chosen. The input/output sound signals are denoted with x_s/ y_s and the input /output gesture signals are denoted with x_g/ y_g .

The LNLQS link has been designed carefully in order to consider it linear for the displacements occurred by the sound input for every "functional point" on the Force/Position curve. Otherwise the system can no longer be approximated as linear and distortion occurs. Additionally effort has been given to preserve a linear relation between the input position and the output amplitude.

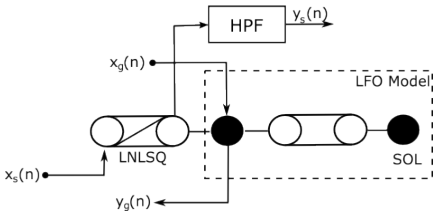

Figure 5 Bend Amplitude Modification Model

The amplitude of the oscillator -LFO model- which is controlled by the external gesture determines the depth of the modulation. Its impedance defines the coupling with the other part of the model: for high impedances its motion is not influenced by the sound input whereas for low values a mutual influence occurs. The parameter S (see figure 2) of the SOL module specifies the transition from ring modulation to amplitude modulation.

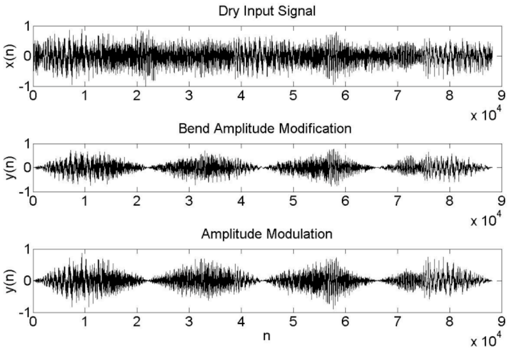

Figure 6 Examples of Amplitude Modulation by the Bend Amplitude Modification Model

3.2. The Mute Amplitude Modification Model

In the second model, the sound file excites a simulated linear physical object such as a string or a simple oscillator. A non linear link which is conditional to position viscoelastic interaction –BUT module- is used to stop and damp the movement of the string. This type of interaction which in the real time situation is defined by the user physical gesture - the hand movement that touches the virtual string - controls the wave propagation and consequently the sound amplitude. The algorithm contains two main blocks: the string and the non linear link.

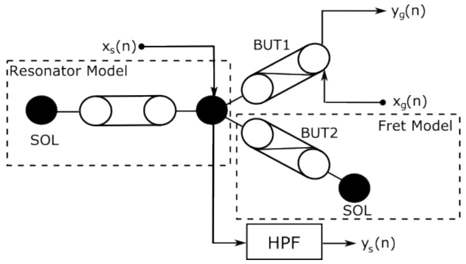

Figure 7 Mute Amplitude Modification Model

In figure 7 the schematic diagram of the algorithm is presented for the simple case of a simple oscillator (Resonator Model). The effect is not a mere amplitude modification: it reminds a combination of distortion, resonator and amplitude modification. In figure 8 we observe the "dry" input audio signal and the "wet" output.

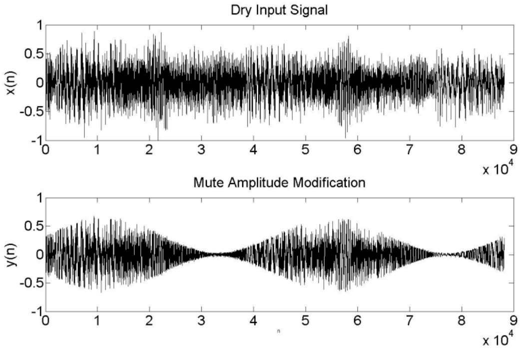

Figure 8 Examples of the Mute Amplitude Modification Model

3.3. The Pluck Amplitude Modification Model

Finally in the third model, the sound file is "attached" to a nonlinear link –LNLK module-. The other side of the link is attached to a stable point. As in the first model, the calculated force from this interaction is the output of the audio effect. The user controls the point in the space where this link is established and the kind or the quality of the interaction. This algorithm may provide heavily distorted sounds depending mostly on the type of the contact-interaction. Figure 9 depicts the diagram of the algorithm. The curve used for the look-up table of the LNLK module is given in figure 10.

Our concept was to provide a physical model which implements an ON/OFF amplitude switch. The algorithm exhibits similarities with plucked stings or plucked oscillator models. A hand that "holds" a sound - for example we can imagine a hand that holds a speaker- and "attach" it to a vibrating structure which diffuse it as the resonance box of a guitar, can give an image of the process.

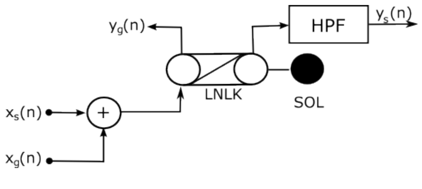

Figure 9 Pluck Amplitude Modification Model

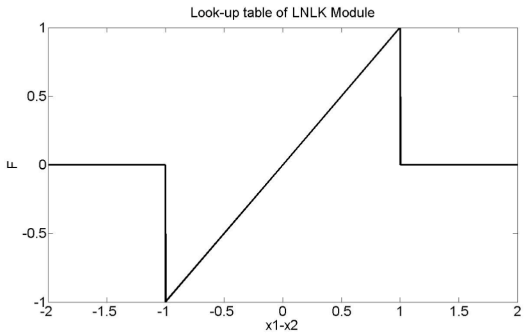

Figure 10 Curve for the look-up table of the LNLK module

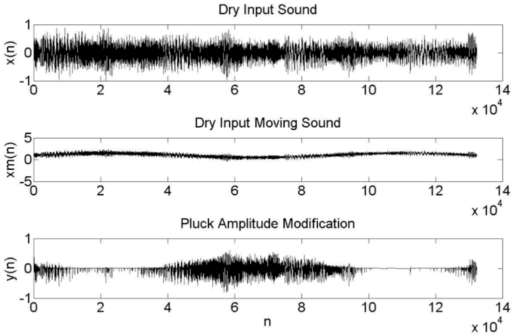

Figure 11Examples of the Pluck Amplitude Modification Model

4. CONCLUSION AND FUTURE WORKS

The aim of this research was to develop and investigate digital signal processing algorithms for sound modification -mainly used for musical purposes- which preserve the important natural instrumental relation found in acoustical musical instruments. In differ-time simulations the models show satisfying agreement between the produced audio output and the desired amplitude modification effect. Most importantly, their structure is physically consistent and hence the system passivity is preserved.

We believe that through this physical dynamic control of the audio effect process, a virtuosity will emerge that will contribute to the quality and the finesse of sound modification. Therefore the next phase of this project concerns the validation of the proposed models in real time conditions with the support of force feedback controllers.

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