Stefania Serafin
Medialogy,
Aalborg University Copenhagen
Lautrupvang 15, 2750
Ballerup
Denmark

sts@media.aau.dk

Russolo's Intonarumori: acoustical description and real-time simulation using physical models

Abstract

Physical models of different Intonarumori, musical instruments invented by the Italian Futurist composer Luigi Russolo, are proposed. The acoustics of the instruments is described, and a physical model to simulate such instruments is proposed.
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Introduction

The Intonarumori (noise intoners) were a family of musical instruments invented in 1913 by the Italian Futurist composer and painter Luigi Russolo. Each instrument was made of a parallelepiped sound box with a speaker on its front. Inside the box, a gut or metal string was excited by a rotating wheel. The speed of the wheel was changed by the performer using a crank, while the tension of the string was varied by using a lever. Such instruments were acoustic noise generators that permitted to create and control several different types of noisy sonorities.
According to Russolo, the Intonarumori created different kinds of everyday sounds, from rumbles to screeches.
The Intonarumori were a consequence of Russolo's theories regarding the structure of the futuristic orchestra.
With the belief that the traditional orchestra needed some new sonority, in his manifesto *The Art of Noises* (Russolo, L. 1916), Russolo proposed taxonomy of noise sounds with six families of noises, divided as follows:

1. Rumbles, roars, explosions, crashes, splashes and booms.
2. Whistles, hisses and snorts.
3. Whispers, murmurs, mumble, grumbles and gurgles.
4. Screeches, creaks, rustle, buzzes, crackles and scrapes.
5. Noise made by percussion on metal, wood, skin, stone, etc.
6. Voices of animal and man: shouts, screams, groans, shrieks, howls, laughs, wheezes and sobs.

The 27 varieties of Intonarumori built by Russolo and his colleagues aimed at simulating such variety of noises. The different names of the instruments were created according to the sound produced: howling, thunder, crackling, crumpling, exploding, gurgling, buzzing, and hissing and so on.
During World War II, all the original Intonarumori got destroyed.
Several attempts to rebuild such instruments were made. Among them, the ones shown in Figure 1 are some reproductions recently shown at the exposition Sounds and Lights at the Pompidou Center in Paris.

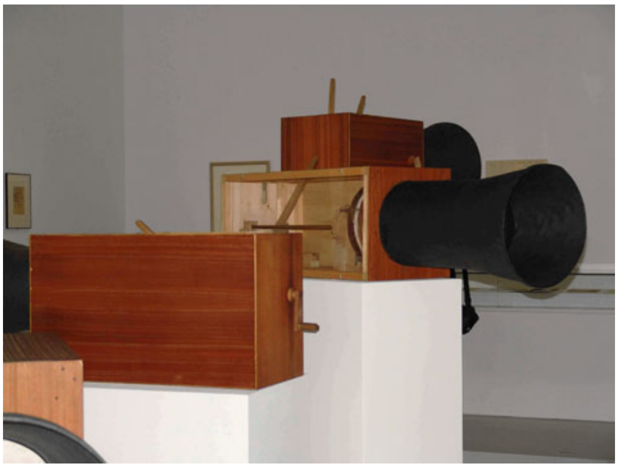

Figure 11. *Different Intonarumori as shows at the exposition Light and Sound in Paris, December 2004.*

In this paper, we describe the acoustics of the instruments belonging to the Intonarumori family, and we propose physical models of such instruments, which work in real-time in the Max/MSP[1] platform, and allow reproducing and extending the everyday sonorities created by Russolo's musical instruments We start by describing the acoustics of the instruments, and then we propose a physical model to simulate them.

[1] www.cycling74.com

Russolo's Intonarumori

As seen in Figure 1, the external appearance of each Intonarumori is similar. Each instrument is made of a sound box with a speaker attached at one extremity. The different timbres of the instruments are mainly do to the excitation mechanism.
Inside the wooden box, a vibrating string is fixed at one hand to the middle of a diaphragm, stretched inside a medium-sized drum, on the other side of which a diffusion horn is mounted.
To play the instruments, the performer turned a crank or pressed an electric button which produced the sound whose frequency was controlled by means of a lever on top of the box.
The use of an electric button allowed a higher speed in the control of the rotating wheel.
The lever could be moved over a scale in tones, semitones and the intermediate gradations within a range of more than an octave.
In the Gracidatore (the Croaker), whose excitation mechanism is shown in Figure 2, the shape of the rotating wheel allows to obtain plucked stringssounds.

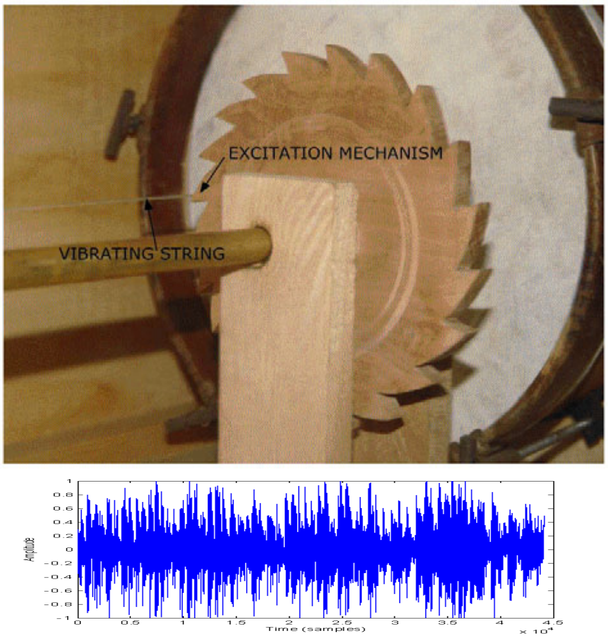

Figure 2. *The excitation mechanism of the Gracidatore (top) and a time domain waveform for one second of sound (bottom).*

In the Crepitatore (the Cracker), shown in Figure 3, the excitation mechanism is a metal wheel, and two levers are present, as well as two vibrating strings.
The reason why two levers where present is not well know, but apparently the two levers allowed to obtain a higher pitch variations of the vibrating string.
In the Ululatore (Howler), described by Russolo as "soft, velvety and delicate", the excitation mechanism was a metal wheel, as shown in Figure 4.

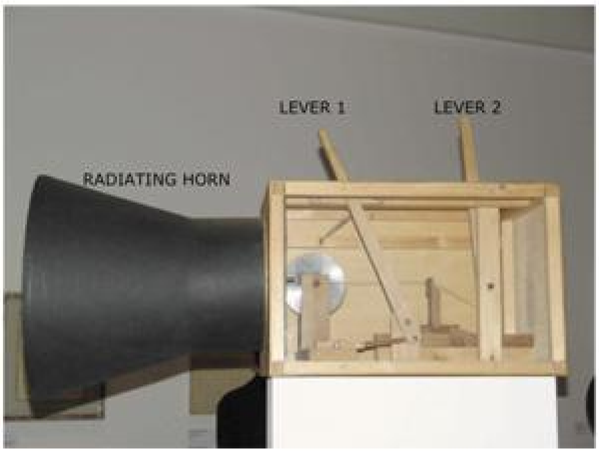

Figure 3. *A reproduction of the Crepitatore. This instrument has two levers.*

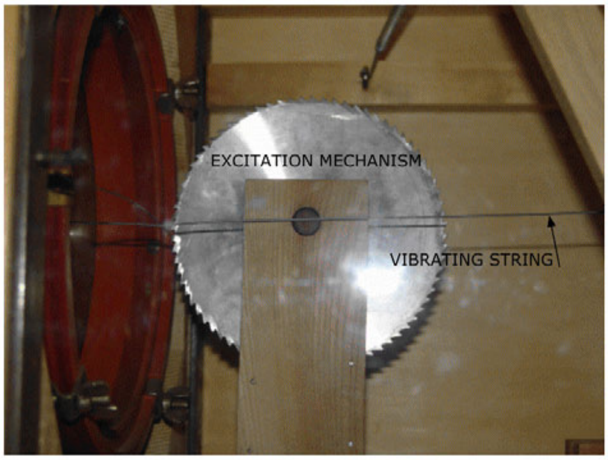

Figure 4. *The excitation mechanism of the Ululatore.*

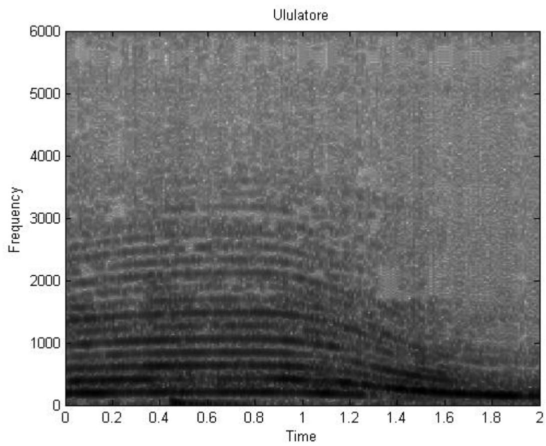

Figure 5. *Spectrogram of two seconds of sound for the Ululatore. Notice the continuous pitch variation obtained by moving the lever attached to the instrument.*

Simulating the Intonarumori

The approach chosen to simulate different Intonarumori relies on the decomposition of a vibrating system into exciter and resonator. The exciting object is modeled as a lumped mechanical system, using a modal description, while the string is modeled using a one dimensional waveguide (Smith, Julius O., 2004). Losses along the string and at the extremities are lumped into a low-pass filter.
The string is simulated by using a delay line of fractional length (Laakso, T. I., Valimaki, V., Karjalainen, M., and Laine, U. K. 1996).
The possibility of changing the tension of the string (which affects the value of the fundamental frequency and allows to obtain glissando and pitch shifting) is obtained by continuously varying the length of the delay line.
Moreover, the string has a high inharmonicity factor, simulated by using allpass filters in cascade.
The string is excited by either by a transient excitation (such as in the case of the Gracidatore) or a sustained excitation (like in the Crepidatore).
To simulate the sustained excitation, we use the elasto-plastic friction model proposed in (Avanzini, F. Serafin, S. and Rocchesso, D. 2002). In this model, the interaction between the rotating wheel and the vibrating string is represented by a differential equation. Fractal noise is added to the model to simulate corrugations in the wheel.
The transient excitation, obtained in rotating wheels such as the one of the Gracidatore, is simulated by using an impact model.
The wooden box of the instrument is modeled by using a 3 dimensional waveguide mesh (Van Duyne, S. and Smith, J.O., 1993).
The dimensions of the mesh are chosen to match the dimensions of the original instrument.
As a final component of the Intonarumori, a radiating horn is attached to one extremity, in order to amplify the sonorities produced inside the box.
We simulate the horn by using one bandpass filter with a high bandwidth, connected to the waveguide mesh resonator as shown in Figure 6.

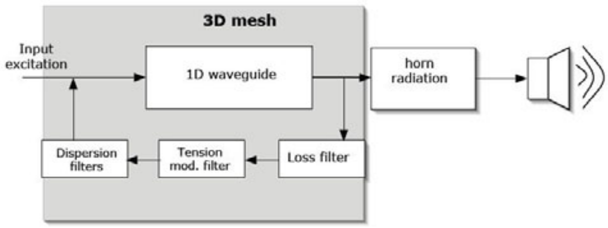

Figure 6. *The complete physical model of the Intonarumori.*

Connecting all together

The different components of the model are connected as shown in Figure 6. The input excitation, either sustained or transient, is connected to the digital waveguide which simulated the string. Inside the waveguide loop, a lowpass filter to simulate losses, a fractional delay filter to simulate tension modulation and an allpass filter to simulate dispersion are present. The waveguide string is placed inside a 3D waveguide mesh which simulates the wooden box of the instrument. Finally the outgoing string velocity is filtered through the radiations of the horn.
The Intonarumori model has been implemented as an extension to the Max/MSP environment.
In the Intonarumori described above, and in the virtual ones too, the control parameters of the instruments are the type of excitation mechanism (plucked or rubbed), which corresponds to the simulation of different instruments of the family,
the angular velocity of the rotating crank, which controls the rotating wheel and is controlled by the player, and the string tension, which corresponds to moving the lever on top of the instrument.

Controlling the instruments

In the original instruments the control parameters given to the player are rather limited. Once the instrument is chosen, the player is only allowed to vary the speed of the rotating wheel and moving the lever back and forth to change the pitch of the string. These limited control possibilities make the instruments not very interesting from a performance perspective. In order to cope with such limitations, we allow additional parameters to be varied in real time such as the size of the soundbox, the
material of the excitation (which can be achieved by changing the parameters of the interaction model and the modal parameters of the exciter), and the physical properties of the vibrating string. Such an extended version of the Intonarumori allows to obtain more interesting sonorities, by controlling and varying the different parameters in real-time.

Conclusions

In this paper we proposed a real-time physical model of some members of the Intonarumori family.
Such computer simulation is useful both from a physical perspective, to comprehend if the sound production mechanism of such instruments has been understood, and to provide a real-time simulation of everyday noise sounds.
Although the performance possibilities of the original Intonarumori are rather limited, the control parameters can be enhanced by building a computer model in which additional parameters can be varied in real-time.
The main challenges encountered in the development of the physical model has been the lack of availability

of the original instruments, which prevented the possibility of measuring their acoustical properties.
The author is currently building a physical reconstruction of the Intonarumori instruments, to perform measurements of their acoustical properties and to enhance such instruments with sensors, to build both a physical musical instrument and a controller for the simulated Intonarumori.

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