EVERYDAY SOUNDS WITH THE DIGITAL INTONARUMORI

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ABSTRACT

A digital simulation of the *Intonarumori*, musical instruments invented by the Italian Futurist composer and painter Luigi Russolo is proposed. By building physical models of different members of the Intonarumori family, a preservation of an important contribution to the musical heritage of the beginning of the 20th century is achieved.

1. INTRODUCTION

At the beginning of the 20th century, the Italian composer and painter Luigi Russolo designed and built a family of new musical instruments which he called Intonarumori (noise intoners). Each Intonarumori was made of a colorful parallelepipedal 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 player by using a crank, while the tension of the string was varied by using a lever. Such instruments were acoustic noise generators which allowed to simulate different everyday noisy sonorities.

Figure 1: *Different Intonarumori as shown in the exposition Sounds and Lights, Paris, Pompidou Center, December 2004.*

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 sonorities, in his Futuristic manifesto *The Art of Noises* [6], Russolo proposed a taxonomy of everyday sounds categorized by six different families. The 27 varieties of Intonarumori built by Russolo and his colleagues aimed at simulating such families of noises.

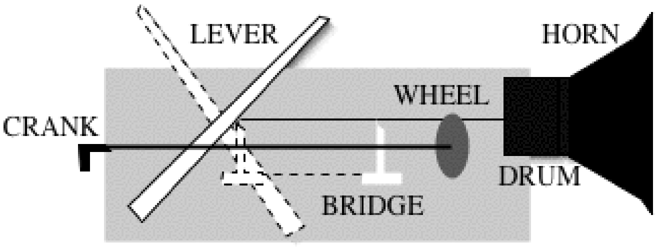

Figure 2: *Schematic representation of a basic Intonarumori. The player, by rotating the crank, rotates the wheel which excites the string. By moving the lever, the tension of the string varies. At the same time, a moving bridge varies the size of the vibrating string. The sound produced resonates thanks to the drum-skin and the radiating horn.*

During World War II, all the Intonarumori got destroyed. Since then, 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.

In this paper, we propose a simulation of different Intonarumori based on physical models. Reproducing these instruments is interesting from different perspectives. On one end, it allows us to understand their acoustics and sound production mechanism. Furthermore, it is possible to relate the source of sound production of everyday sounds to the way they are perceived, i.e., it is possible to find a link between spectral and physical models. Finally, revitalizing the Intonarumori allows the instruments to become known to a wider audience.

2. RUSSOLO'S INTONARUMORI

Figure 1 shows several kinds of Intonarumori, rebuilt after documentation obtained through Russolo's patents and letters. The external appearance of each Intonarumori is rather similar. Each instrument is made of a sound box with a radiating horn attached at one extremity. The different timbres of the instruments are mainly due to the different excitation mechanisms, and are the origin of their names.

As an example, in the *Gracidatore* (the Croaker), whose excitation mechanism is shown in Figure 3, the shape of the rotating wheel allows to obtain plucked string sonorities. The wheel, rotating at a speed controlled by an external crank, excites a vibrating string attached at two extremities of the wooden sound-box. The player, as in the other instruments, is able to control the tension of the string by using an external lever.

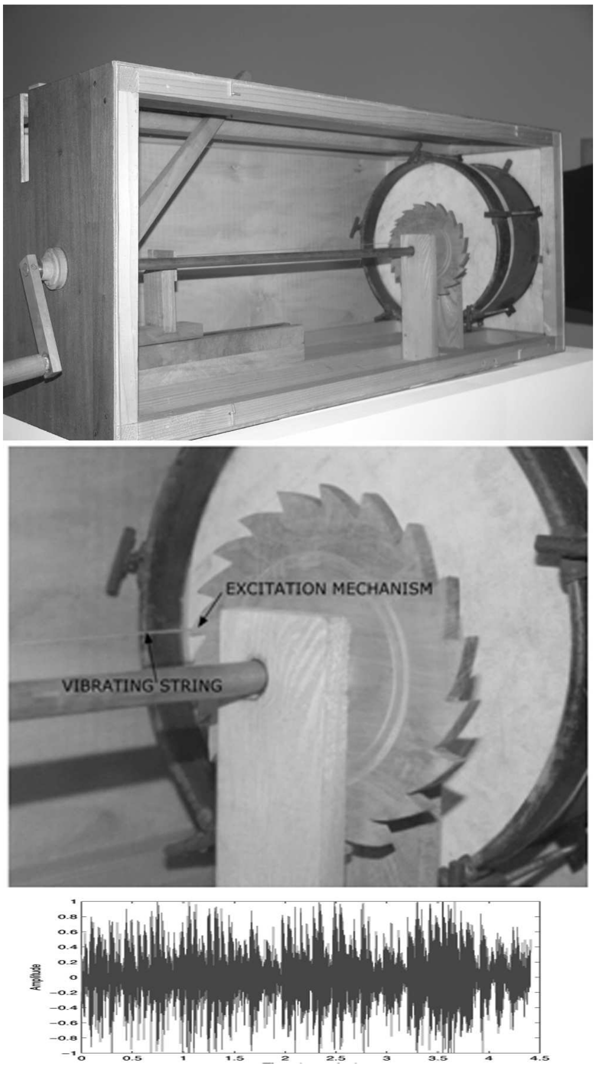

Figure 3: *A reproduction of the Gracidatore (top), its excitation mechanism (center) and a time domain waveform for one second of sound (bottom).*

In the Crepitatore (the Cracker), shown in Figure 4, the excitation mechanism is a metal wheel, and two levers are present, as well as two vibrating strings. This allowed the string attached to the drum-skin to be different from the one excited by the rotating wheel. The same idea was also adopted in the Stroppicciatore (the Rubber). Documents and patents did not succeed in explaining the role of the two strings in the resulting sonorities produced by the instruments. In the Ululatore (Howler), described by Russolo as "soft, velvety and delicate", shown in Figure 5, the excitation mechanism was a smooth wooden wheel.

Russolo and his assistant Ugo Piatti researched all the physical aspects that could be varied in order to obtain different timbres and sonorities, in order to achieve a satisfactory simulation of the families of noises described above [5].

As an example, the string was either steel or gut, the wheel either metal or wood, with its rim notched with small teeth or smoother, and the skins were soaked in a variety of special chemical preparations. Furthermore, the pressure of the wheel against the string, stronger than is necessary with a violin bow, created a louder and noisier sound quality.

Russolo also experimented with more radical Intonarumori, based on electrical rather than mechanical control, such as the one used in the Hummer (Ronzatore), which was more a percussion than a string instrument. It has been suggested that the electrical control might have been due to the need for a speed that was too rapid to have been achieved manually. As a supplementary enhancement, a second lever was added in the Burster (Scoppiatore), the Whistler (Sibilatore) and the Gurgler (Gorgogliatore). In his writings, Russolo does not explain the need for the second lever.

Table 1 summarizes the different members of the Intonarumori family. On the left side, the name of each instrument is listed. In the center, their sonic characteristic is described, while on the right side the physical characteristics of the instruments are illustrated. Notice how some items of the Table are left blank. This is due to the reason that documentation regarding some instruments has been lost.

Name	**Perceived sonority**	**Source**
Crepitatore Crackler	creaks	metal wheel, small teeth
Ronzatore Hummer	buzzes	Electrical control, percussion
Gracidatore Croaker	Voices of animals	plucked excitation
Ululatore Howler	whistles, hisses	smooth wooden wheel
Gorgogliatore Gurgler	Groans	Percussive excitation
Rombatore Rumbler	rumbles, roars	
Scoppiatore Burster	explosions	two levers
Sibilatore Whistler	whispers	two levers
Stroppicciatore Scraper	Crackles	two strings
Scrosciatore	screeches	
Tuonatore Thunderer		
Frusciatore Rustler		

Table 1: *First column: members of the Intonarumori family. Second column: sonorities created by the instruments, according to the six families proposed in [6]. Third column: physical characteristics of the instruments. The classification is mainly based on [6]. The elements left blank corresponds to lack of information.*

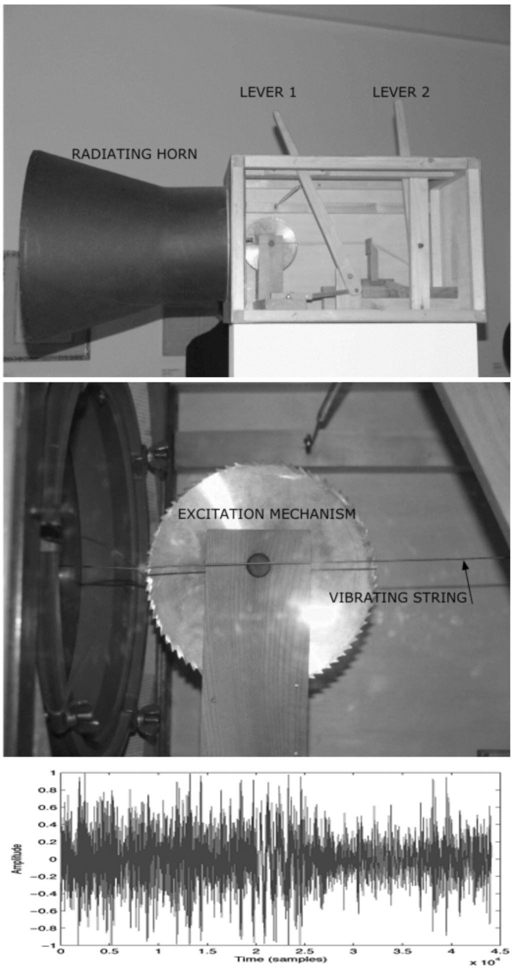

Figure 4: *Reproduction of the Crepitatore (top). In this instrument, two levers are present. Center: a close-up to the excitation mechanism; bottom: time domain waveform obtained by playing the instrument for one second. Notice the noisy waveform.*

3. MODELING THE INTONARUMORI

We developed a physical model of three kinds on Intonarumori, the Croaker, the Howler, and the Cracker.

The physical model of these instruments is based on previous research on waveguide string models with tension modulation [9], transient and sustained excitations mechanisms and 2D and 3D waveguide meshes.

Given the lack of availability of a physical Intonarumori, the parameters of the different components of the model are not derived from analysis of the instruments, but rather empirically obtained by listening to the resulting sonorities.

3.1. Modeling the vibrating string

The approach to simulation relies on the decomposition of a vibrating system into excitation 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 [7]. Losses along the string and at the extremities are lumped into a low-pass filter. In order to allow to continuously vary the fundamental frequency of the string, the tension modulation algorithm proposed in [9] was implemented. The effect is obtained by using a time-varying fractional delay filter, as shown in [10].

Different string materials were simulated by using allpass filters, added in cascade to the string loop. The string is excited by either a transient excitation (Croaker) or a sustained excitation (Howler and Cracker). Such mechanisms are described in the following.

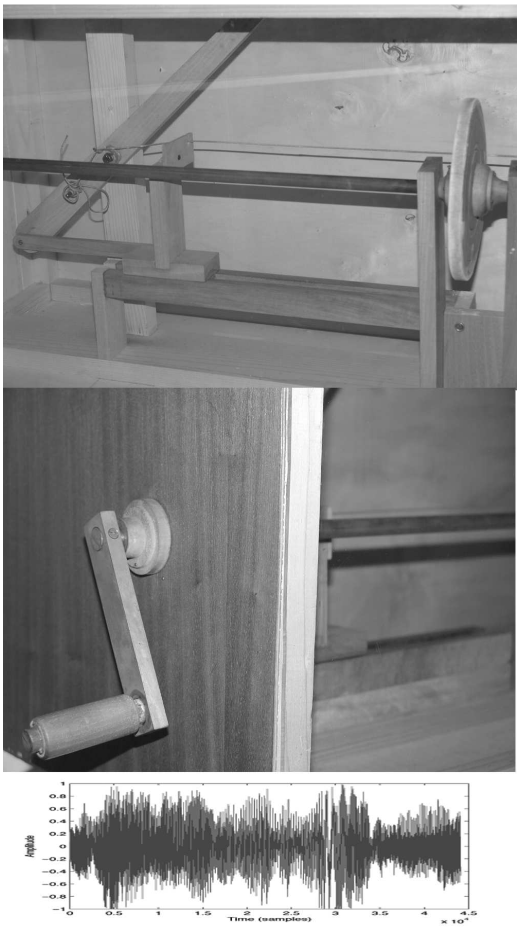

Figure 5: *Reproduction of the Ululatore (top), and close-up to the external crank (center). Bottom: time domain waveform obtained by playing the instrument for one second. Notice the noisy waveform.*

3.2. Modeling the excitation mechanism

3.2.1. Transient excitation

In order to simulate a transient excitation between the vibrating wheel and the string, a model of a plucked excitation mechanism such as the ones proposed in [7] is adopted. The transient excitation in the Intonarumori is perceived as a highly inharmonic plucked string, and the frequency of plucking is given by the rotational speed of the wheel divided by the number of bumps present

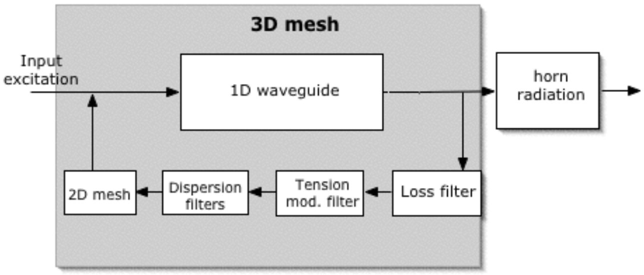

Figure 6: *Structure of the physical model of an intonarumori. The input excitation can be either sustained or transient, as described in the text. Loss filters for damping, tension modulation fractional delay filters and allpass filters for dispersion are added to the string loop. The resonances of the string excite the 2D mesh, and are filtered through the sound-box model, before becoming the output to the horn resonator, and being heard by the listener.*

in the wheel itself.

3.2.2. Sustained excitation

To model the sustained excitation between the rotating wheel and the string, the elasto-plastic friction model proposed in [2], and already adopted for sound synthesis purposes in [1], was used. The idea behind this modeling approach is that at contact point objects exhibit a random bristle behavior, captured and averaged in a single-state system. Applying a tangential force affects the average bristle deflection and, if the deflection is large enough, the bristles start to slip. The class of elasto-plastic models proposed by Dupont and colleagues can be described by the equations

$$\dot{z} = f_{NL}(v,z) = v\left[1-\alpha(z,v)\frac{z}{z_{ss}(v)}\right]\ , \dot{z} = v - \frac{|v|}{g(v)}z\ , \tag{1}$$

$$f_f = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 v + \sigma_3 \omega, \tag{2}$$

where z is the average bristle deflection, v is the relative velocity between the two surfaces, σ_0 is the stiffness of the bristles, σ_1 is the bristle damping, $\sigma_2 v$ accounts for linear viscous friction, $\sigma_3\omega$ is a stochastic component due to the irregularities of the excitation, and f_f is the resulting friction force.

For details on the friction model, see [1]. Notice that, when connecting the modal exciter to the waveguide resonator through a nonlinear interaction, the resulting system exhibits computational problems since a delay free path is generated. As shown in [3], and efficient solution is given by the so-called K-method.

3.3. Modeling the drum-skin

In instruments such as the Croaker, the role of the drumskin is strongly perceivable. The vibration of the string excites the drum which resonates through the horn. We modeled the drum by using a two dimensional waveguide mesh, excited by the vibrating string [8].

3.4. Modeling the sound box

The sound box is simulated by using a three dimensional waveguide mesh [8]. The dimensions of the mesh are chosen to match those of a parallelepipedal box. The wooden material of the box is simulated by using a low-pass filter.

From a physical point of view, the wooden sound box acts as a small reverberator for the sound produced inside the intonarumori.

The string, together with the excitation mechanism and the 2D waveguide mesh which simulates the drum-skin, are placed inside the 3D mesh, as shown in Figure 6. This means that a simulation of the Intonarumori requires a physical model (the string, either plucked or rubbed) inside another physical model (the sound box). At each time sample, the vibration of the string is calculated, by solving the interaction between the excitation mechanism and the string model.

The samples of the string attached at the extremity where the horn is located are calculated, by using the mesh model as the reverberator. Finally, the string vibration is radiated through the external horn, whose simulation is described in the following.

3.5. Modeling the radiating horn

As a final component of the Intonarumori, a radiating horn is attached to one extremity. We simulate the horn by using one bandpass filter with a high bandwidth, connected to the waveguide mesh resonator as shown in Figure 6.

3.6. Connecting all together

The different components of the model are connected as shown in Figure 6. The excitation of the model, either transient or sustained, allows a string to vibrate. The decay characteristics of the vibrating string are simulated by using a one-pole low-pass filter, while the tension modulation filter simulates the effect of moving the crank in order to vary the fundamental frequency of the vibrating string. In order to simulate strings of different materials, allpass filters are added to the string loop. The string is connected to a 2D waveguide mesh in parallel, and placed inside a 3D mesh simulating the sound-box, acting as a small box resonator. As a final simulation component, a radiating horn simulated using a bandpass filter is added before the listener's output.

4. SIMULATION RESULTS AND IMPLEMENTATION

4.1. Real-time optimization

Although the model proposed in the previous section is accurate from the physical point of view, it is not efficient for a real-time implementation. In particular, the cost of the 3D waveguide mesh prevents computational efficiency.

In order to implement the Intonarumori model in real-time, in particular as an extension to the Max/MSP environment [1], we made some implementational choices. In particular, we decided to remove the 3D mesh simulation. It appears that the mesh does not significantly contribute to the already rich timbre of the instruments, although listening tests should be performed to confirm such a statement.

In the Intonarumori originally designed by Russolo, 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 rotational velocity of the excitation wheel, controlled by the player through the external

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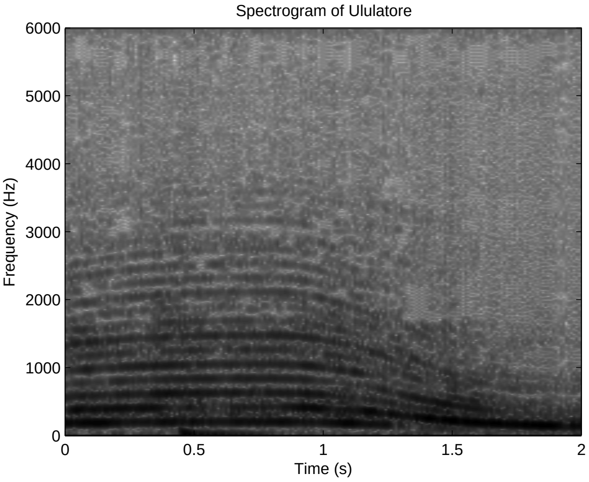

Figure 7: *Spectrogram of the Ululatore. Notice the effect of tension modulation in the variation of the frequency component of the string.*

crank, and the string tension, controlled by the player by moving the lever on top of the instrument.

The same control parameters are also present in the model. Figure 7 shows the spectrogram of the Ululatore, when the tension parameters is varied. Notice the effect of tension modulation in the resulting spectrum. Figure 8 shows the spectrogram of the Gracidatore. The plucking events are clearly noticeable in the spectrum. Figure 9 shows the spectrogram of the Crepitatore.

5. CONCLUSION

In this paper we introduced the Intonarumori, a family of musical instruments designed in the Futuristic period by Luigi Russolo. We find the study of these instruments interesting from different perspectives: first of all, it is possible to preserve the work of a designer which was criticized by the general audience for his highly innovative instruments, but also instigated the curiosity of several composers such as Stravinsky and Ravel. Moreover, we are currently building a physical reproduction of the Intonarumori enhanced with rotary and position sensors attached to the wheel and the lever, in order to use the physical reconstructed instrument to control real-time audio and visual effects. By having these new Intonarumori interact in real-time with their virtual counterpart, it is possible to explore new sonorities and cope with the sonic limitations of the original instruments, which could have been one of the reasons of their unsuccess. Unfortunately, since all instruments got destroyed during World War II, we can only find documentations of their shape and acoustical properties through reconstructions, documents and patents. Our physical reconstruction allows to achieve a better understanding of the mechanics of the instruments, and validate the physical model as well as hopefully help in filling some gaps on the current knowledge regarding these instruments.

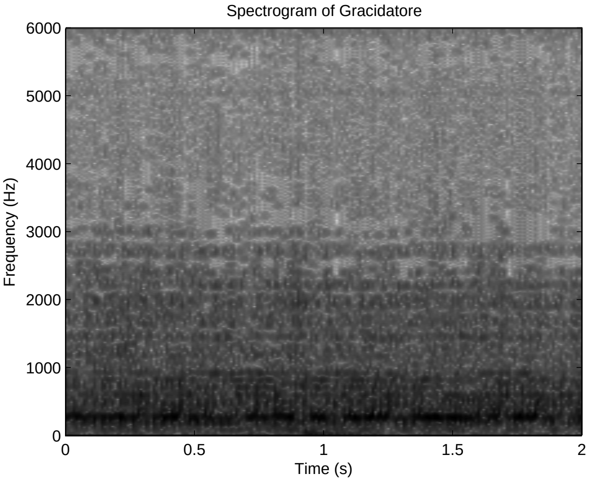

Figure 8: *Spectrogram of the Gracidatore. The transient excitation mechanism is clearly noticeable.*

5.1. Acknowledgments

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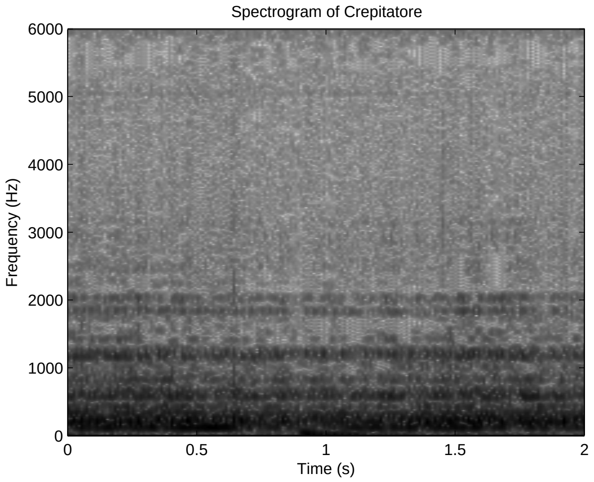

Figure 9: *Spectrogram of the Crepitatore.*

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