# THE CROAKER: DESIGN AND EVALUATION OF A NEW MULTIMODAL INTERFACE

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## ABSTRACT

In this paper we introduce the Croaker, a novel input device inspired by Russolo's Intonarumori. We describe the motivations behind the design of this instrument, and its applications in human computer interaction (HCI) and music.

## 1. INTRODUCTION

Real-time gestural control of computer generated sounds has become in the past years a common trend in the computer music community. A conference dedicated to this topic, called NIME (which stands for New Interfaces for Musical Expression) has been created in 2001, and several new input devices have been designed [14, 6].

Such devices can be classified as 1) instrument-like controllers, which try to emulate the control interfaces of existing acoustical instruments; 2) instrument-inspired controllers, which follow characteristics of existing instruments; 3) extended instruments, i.e., acoustical instruments augmented with sensors and 4) alternate controllers, whose design does not follow any traditional musical instrument [15].

In this paper, we are interested in designing a controller inspired by the Intonarumori musical instruments family. The Intonarumori (noise intoner) were a family of musical instruments designed and built around 1913 by the Italian composer and painter Luigi Russolo. Such instruments were acoustic noise generators which allowed to simulate different everyday noisy sonorities.

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 sonorites, in his Futuristic manifesto *The Art of Noises* [9], Russolo proposed a taxonomy of noisy sounds having six families of noises, divided as follows:

- Rumbles, roars, explosions, crashes, splashes and booms.
- Whistles, hisses and snorts.
- Whispers, murmers, mumbles, grumbles and gurgles.
- Screeches, creaks, rustles, buzzes, crackles and scrapes.
- Noise made by percussion on metal, wood, skin, stone, etc.
- Voices of animal and man: shouts, screams, groans, shrieks, howls, laughs, wheezes and sobs.

In this paper we introduce the Croaker, a new interface shown in Figure 6 inspired by Russolo's Intonarumori. Section 2 describes the different instruments belonging to the original Intonarumori family, Section 3 describes the Croaker, Section 4 describes the sound synthesis engine connected to the Croaker, Section 5 shows the Max/MSP implementation and Section 6 presents conclusions and future work.

## 2. RUSSOLO'S INTONARUMORI

Figure 1 shows Luigi Russolo and his colleague Ugo Piatti playing the original Intonarumori at around 1913. As

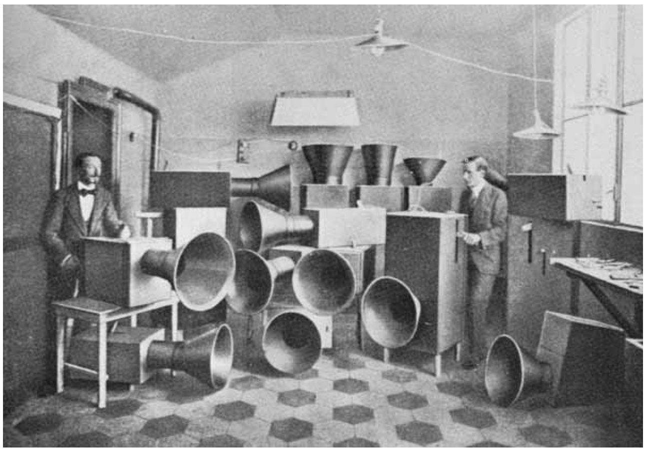

**Figure 1**. *Russolo and his colleague Ugo Piatti playing the original Intonarumori. From [8].*

can be seen in the Figure, each Intonarumori was made of a parallelepipedal box, with a crank and a lever in the outside. The player, by rotating the crank, was able to rotate a wheel placed inside the box, which excited a vibrating string. The string, stretched at the two extremities of the box, was attached to a vibrating drum connected to a radiating horn. By moving the lever back and forth, it was possible to change the tension and length of the vibrating string, and therefore its fundamental frequency.

The 27 varieties of Intonarumori built by Russolo and his colleagues aimed at reproducing such varieties of noises. The different names of the instruments were assigned according to the sound they produced. As an example, in the *Gracidatore* (the Croaker), whose excitation mechanism is shown in Figure 2, 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 soundbox. The player, as in the other instruments, is able to control the tension of the string by using an external lever.

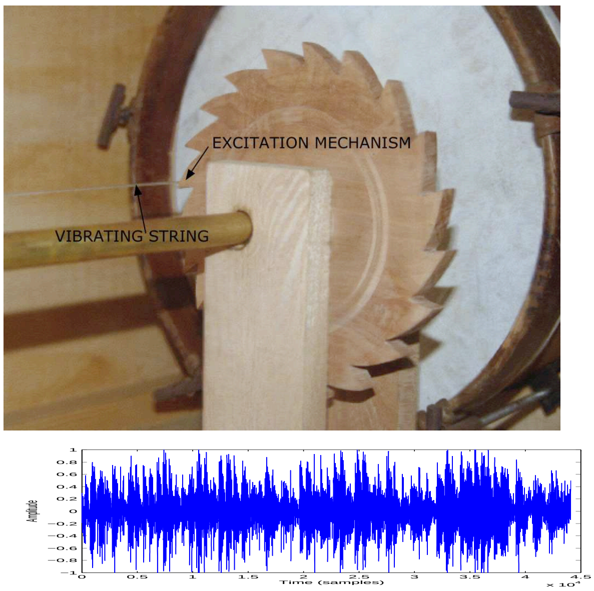


**Figure 2**. *The excitation mechanism of the Gracidatore (top) and a time domain waveform for one second of sound (bottom).*

In the Crepitatore (the Cracker), show in Figure 3, 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 drumskin 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 4, the excitation mechanism was a metal wheel.

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

As an example, the string was made of either steel or gut, the wheel was made of metal or wood, with its rim

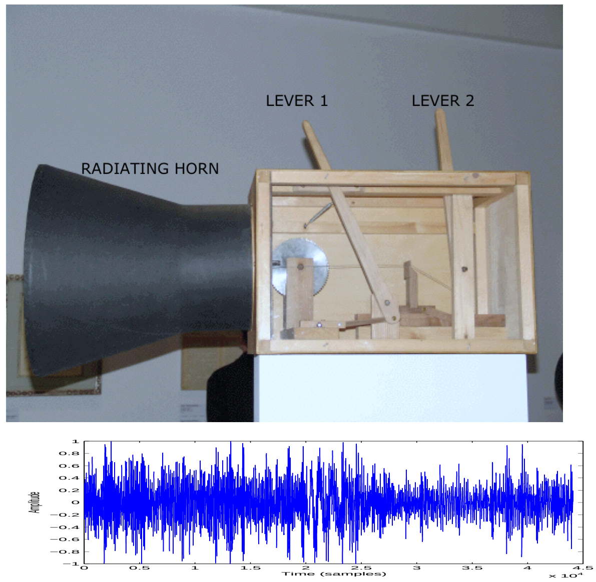


**Figure 3**. *Reproduction of the Crepitatore (top). In this instrument, two levers are present. Bottom: time domain waveform obtained by playing the instrument for one second. Notice the noisy waveform.*

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 such second lever.

During World War II, all the original Intonarumori got destroyed. Since then, several attempts to rebuild such instruments were made. Among them, the ones shown in Figure 5 are some reproductions displayed at the exposition Sounds and Lights at the Pompidou Center in Paris in December 2004.

## 3. THE CROAKER

In the attempt to create a modern reconstruction of Russolo’s Intonarumori, which could be used both as a musical instrument on its own and as an interface for real-time audio-visual synthesis, we designed the Croaker, shown in Figure 6.

In its first prototype, the Croaker is an interface built with Lego blocks. The name of the instrument derives from one of the original Russolo’s instruments.

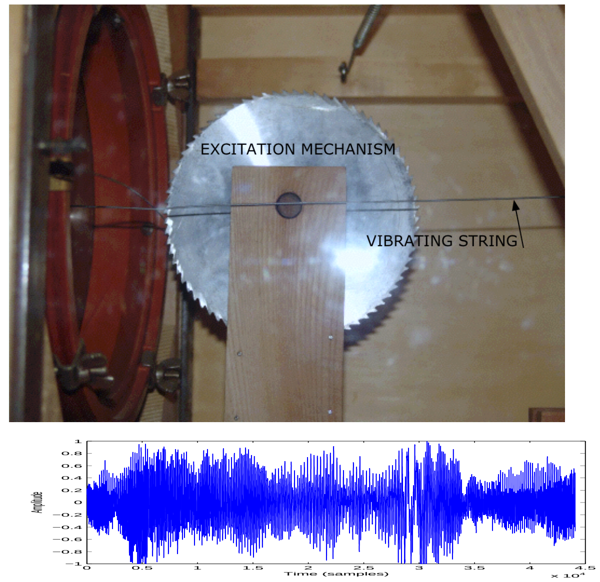


**Figure 4**. *The excitation mechanism of the Ululatore (top), and a one second time domain waveform (bottom).*

As in the original Intonarumori, the Croaker is provided with a one degree of freedom lever moving vertically, and a rotating crank. The position of the lever is detected by a potentiometer, attached as shown in Figure 7. The rotation of the crank is also sensed by a different potentiometer, attached to the wheel as shown in Figure 7. Both sensors send a continuous stream of data. The current prototype of the Croaker is shown in Figure 8. Compared to the one shown in Figure 6, the instrument has a more compact shape, and a linear slider is provided. Such slider allows to vary the pitch range of the instrument.

The variables sensed by the current prototype of the Croaker are illustrated in Figure 9 [5]. The three circles in Figure 9 represent the rotational position sensed by the potentiometer connected to the lever and the rotational position sensed by the potentiometer connected to the crank. Moreover, a continuous slider is added. Since both the potentiometer and the lever connected to the slider are controlling the fundamental frequency of the instrument, they are connected by a solid black line.

The sensors are attached to a Teleo microprocessor manifactured by Making Things. [1] The microprocessor is connected to a computer through the USB port.

By using the Max/MSP and Jitter software, [2] some adhoc external objects have been developed which convert the data sent by the sensors into numerical input which can be read by Max. Such data are used as controllers to several audio-visual simulations, as described in the following section.

The Croaker is an interface which is easy to learn how to play. It is played by controlling the position of the lever with the left hand, while rotating the crank with the right hand. It is also possible to vary the pitch range of the instrument by using the linear slider.

[1] www.makingthings.com
[2] www.cycling74.com

**Figure 5**. *Different Intonarumori as shown in the exposition Sounds and Lights, Paris, Pompidou Center, December 2004.*

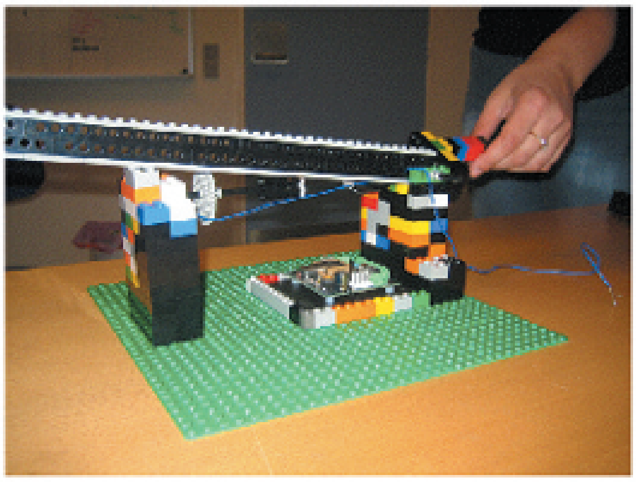

**Figure 6**. *The first prototype of the Croaker: a new interface inspired by Russolo's Intonarumori.*

## 4. THE SOUND SYNTHESIS ENGINE

The Croaker is a controller which can drive several sound synthesis algorithms. We developed a physical model of two kinds of Intonarumori, the Croaker and the Howler, based on a plucked and rubbed excitation mechanism respectively.

The physical model of such instruments is based on previous research on waveguide string models with tension modulation [12], transient and sustained excitations mechanisms.

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 by empirically adjusting the parameters of the physical model.

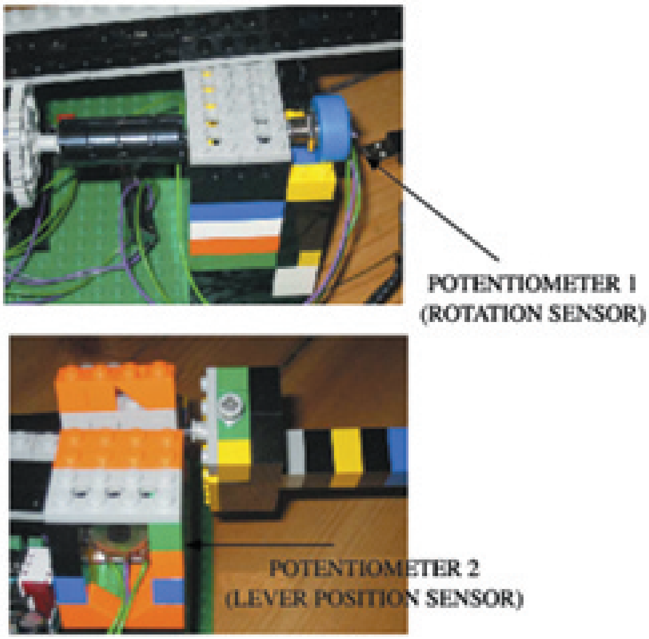


**Figure 7**. *Placement of the two potentiometers in the Croaker.*

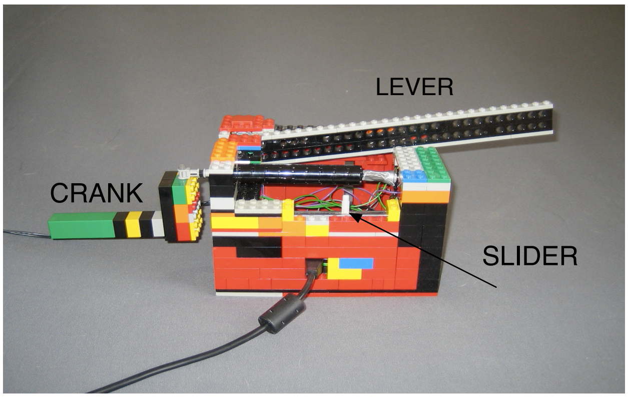


**Figure 8**. *The current prototype of the Croaker.*

### 4.1. 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 [10]. 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 [12] was implemented. Such effect is obtained by using a time-varying fractional delay filter, as shown in [13].

Different string's properties were simulated by using allpass filters, added in cascade to the string loop. The string is excited by either a transient excitation (such as in the case of the Gracidatore) or a sustained excitation (like in the Crepidatore). Such mechanisms are described in the following.

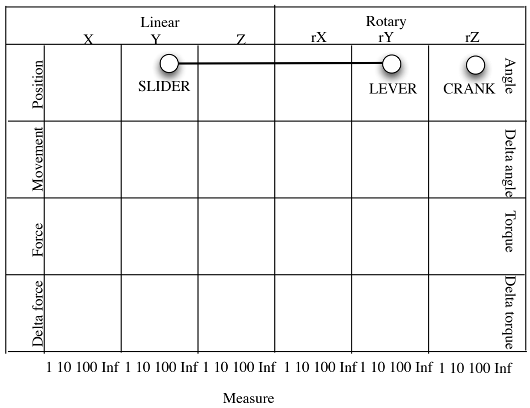


**Figure 9**. *Types of variables sensed and resolution of the Croaker. From [5].*

### 4.2. Modeling the excitation mechanism

#### 4.2.1. 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 [10] 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 in the wheel itself.

#### 4.2.2. Sustained excitation

To model the sustained excitation between the rotating wheel and the string, the elasto-plastic friction model proposed in [3], and already adopted for sound synthesis purposes in [1], is 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

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

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

where $z$ is the average bristle deflection, $v$ is the relative velocity between the two surfaces, $\sigma_0$ is the stiffness of the bristles, $\sigma_1$ is the bristle damping, $\sigma_2 v$ accounts for linear viscous friction, and $f_f$ is the resulting friction force.

The auxiliary functions $\alpha$ and $z_{ss}$ can be parametrized in various ways. Here we follow [3] by defining $z_{ss}$ as

$$z_{ss}(v) = \frac{\mathrm{sgn}(v)}{\sigma_0}\left[f_c + (f_s - f_c)e^{-(v/v_s)^2}\right] \quad , \tag{3}$$

where $f_c, f_s$, are the Coulomb force and the friction force respectively, and $v_s$ is the Stribeck velocity (the subscript $ss$ in $z_{ss}$ stands for "steady-state"). As far as $\alpha$ is concerned, we follow [3] by defining it as

$$\alpha(v,z) = \left\{ \begin{array}{ll} 0 & |z| < z_{ba} \\ \alpha_m(v,z) & z_{ba} < |z| < z_{ss}(v) \\ 1 & |z| > z_{ss}(v) \\ 0 \quad \text{if } \mathrm{sgn}(v) \neq \mathrm{sgn}(z) & \end{array} \right\} . \tag{4}$$

The function $\alpha_m(v,z)$, which describes the transition between elastic and plastic behavior, is parametrized as

$$\alpha_m(v,z) = \frac{1}{2}\left[1 + \sin\left(\pi \frac{z - \frac{1}{2}(z_{ss}(v) + z_{ba})}{z_{ss}(v) - z_{ba}}\right)\right] . \tag{5}$$

Therefore the parameter $z_{ba}$ defines the point where $\alpha$ starts to take non-zero values, and is termed *breakaway displacement*.

In order to account for irregularities of the rotating wheel, fractal noise was added to the friction function of Eq.2.

### 4.3. Modeling the drum-skin

In the original Intonarumori, the vibrating string excites a drumskin. The vibration of the drumskin strongly contributes to the timbre of the instruments. In order to simulate the drumskin, we designed a 2D waveguide mesh, as proposed in [11].

## 5. IMPLEMENTATION

The Intonarumori model has been implemented as an extension to the Max/MSP environment.[3] 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 crank, and the string tension, controlled by the player by moving the lever on top of the instrument. Additionally, it is possible to control the frequency range of the vibrating string by using a continuous linear slider. Figure 10 shows the Max/MSP patch which simulates the Ululatore. In this patch, it is possible to identify three main components. The top part contains the objects which implement the connection between the Teleo sensors board and Max/MSP. These objects are already available from the Teleo website. The central part contains the mapping strategies to connect the data of the sensors to the sound synthesis engine. The position of the lever is mapped linearly to the fundamental frequency of the string. The fundamental frequency of the string can also be varied by using the linear slider. The rotational velocity of the crank is obtained by calculating the derivative of the position, and mapped to the excitation velocity. In the case of a transient excitation, the excitation velocity affects the number of bumps per second. In the case of the sustained excitation, the velocity affects the exciter velocity. As is the case in the original instruments, the excitation force cannot be controlled by the player, but it is predefined in the physical model. Similarly, the parameters of the friction model, as well as the inharmonicity of the string, are predefined, and allow to simulate different instruments from the Intonarumori family.

[3] www.cycling74.com

## 6. SIMULATION RESULTS

As an example, we created a physical model of the Ululatore, instrument in which a sustained excitation is present. Figure 11 shows the spectrogram of the Ululatore, when the tension parameters is varied. Notice the effect of tension modulation in the resulting spectrum.

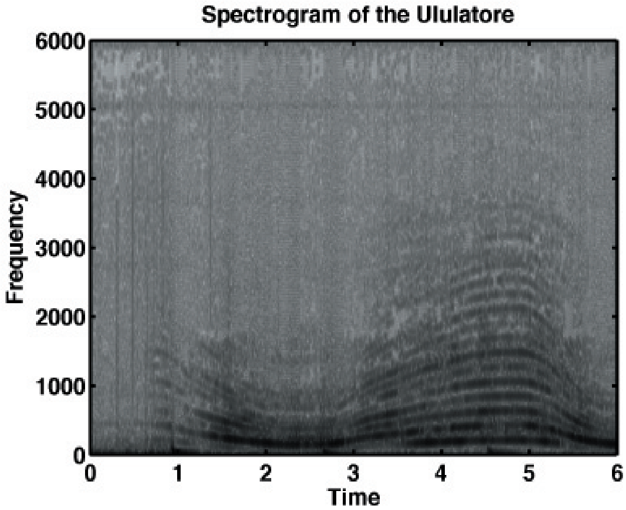


**Figure 11**. *Spectrum of the simulated Ululatore. Notice the effect of tension modulation.*

## 7. CONCLUSION

In this paper we introduced the Croaker, a new input interface inspired by Luigi Russolos Intonarumori. We are currently experimenting with the Croaker as a controller for HCI experiments. We are examining the potentials of the Croaker as a new input device, and we are studying different mapping strategies. We are also designing a more compact version of the instrument, in which the mechanical devices and sensors remain the same, but the size and shape of the instrument is better defined. We are also adding a soundbox and a radiating horn to the interface, in order to obtain a more faithful reproduction of Russolos original instrument.

## 8. REFERENCES

[1] F. Avanzini, S. Serafin, D. Rocchesso. Modeling Interactions between Rubbed Dry Surfaces Using an Elasto-Plastic Friction Model. Proc. DAFX 2002, Hamburg, Germany.

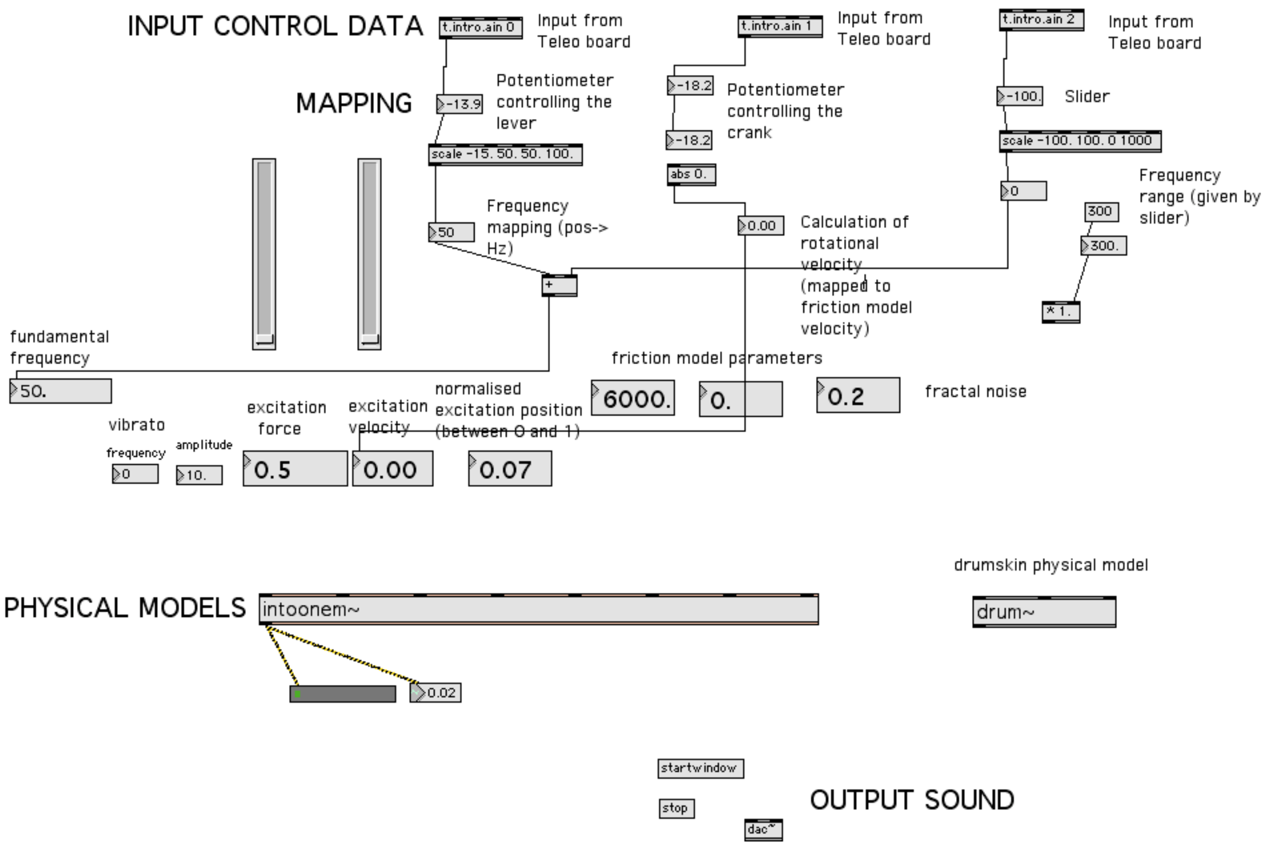


**Figure 10**. *The Max/MSP patch which simulates the Intonarumori physical model. On the top part of the patch there are the instructions to gather data from the three sensors. In the central part the mapping between the sensors and the physical model is implemented. In the bottom part, the external objects simulate the intronarumori interaction between the excitation and the string, as well as the drumskin.*


[2] F. Avanzini and D. Rocchesso, Modeling Collision Sounds: Non-linear Contact Force, Proc. COST-G6 Conf. Digital Audio Effects (DAFx-01), Limerick, 2001, pp. 61-66.

[3] P. Dupont, V. Hayward, B. Armstrong and F. Altpeter (2002). "Single State Elasto-Plastic Friction Models," IEEE Transactions on Automatic Control, Vol. 47, No. 5, pp. 787-792.

[4] G. Borin, G. De Poli and D. Rocchesso. Elimination of delay-free loops in discrete-time models of nonlinear acoustic systems. Speech and Audio Processing, IEEE Transactions on ,Volume: 8 , Issue: 5 , Sept. 2000 Pages:597 - 605

[5] Card, S.K, Mackinlay, D. and Robertson, G.G. A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems, Vol. 9, No. 2, April 1991, Pages 99-122.

[6] Cook, P. Principles for Designing Computer Music Controllers. Proc. CHI 2001.

[7] Laakso, T. I., Valimaki, V., Karjalainen, M., and Laine, U. K. 1996. Splitting the unit delay-tools for fractional delay filter design. IEEE Signal Processing Magazine, vol. 13, no. 1, pp. 30-60.

[8] Maffina. G. Luigi Russolo e l'Arte dei rumori, con tutti gli scritti musicali. Torino: Martano editore, 1978.

[9] Russolo, L. L'arte dei rumori (The Art of Noise). Edizioni Futuriste di Poesia, 1916.

[10] Smith, Julius O. Physical Audio Signal Processing: Digital Waveguide Modeling of Musical Instruments and Audio Effects, August 2004 Draft, Center for Computer Research in Music and Acoustics (CCRMA), Stanford University.

[11] S. Van Duyne and J.O. Smith. Physical modeling with the 2D waveguide mesh. In Proc. Int. Computer Music Conf. (ICMC'93), pages 40–47.

[12] V. Valimaki and T. Tolonen and M. Karjalainen. Plucked-string synthesis algorithms with tension

modulation nonlinearity. IEEE International Conference on Acoustics, Speech and Signal Processing, Phoenix, Arizona, March 1999.

[13] V. Valimaki, T. Tolonen, and M. Karjalainen. Signal dependent nonlinearities for physical models timevarying fractional delay filters. Proc. Int. Music Conf., Ann Arbor, MI, Oct. 1998.

[14] Wanderley, M. and Battier, M. (eds). Trends in Gestural Control of Music. Ircam - Ircam, Centre Pompidou, 2000.

[15] Wanderley, M. and Orio, N. Evaluation of Input Devices for Musical Expression: Borrowing tools from HCI. Computer Music Journal, 26:3, 2003.

[16] S. Serafin, J.O. Smith III and J. Woodhouse. An investigation of the impact of torsion waves and friction characteristics on the playability of virtual bowed strings. Proc. IEEE WASPAA, 1999.