

# Sharp Colliding of multiple sound objects with Haptic Feedback.

*Jean-Loup Florens*

A.C.R.O.E.  
Ministère de la Culture  
ICA Laboratory  
INPG 46, Av. Felix Viallet 38000  
Grenoble – France  
*florens@imag.fr*

*Annie Luciani*

ICA Laboratory  
(Informatique et Création Artistique)  
INPG, 46 av. Félix Viallet,  
38000 Grenoble, France  
*Annie.Luciani@imag.fr*

*Nicolas Castagné*

ICA Laboratory  
(Informatique et Création Artistique)  
INPG, 46 av. Félix Viallet,  
38000 Grenoble, France  
*Nicolas.Castagne@imag.fr*

## ABSTRACT

The paper presents a real time interactive synthesis of a child rattle that exhibits sharp collision effects. This synthesis is made of an efficient implementation from a particle based physical model that integrates both spatial and vibratory properties. The article present a specific modeling technique employed and experimental results that highlight both the interest of such instrumental simulation but also the drastic dynamics requirements that are necessary in their implementation.

## 1. INTRODUCTION

Physical modeling is since many years a common mean to synthesize musical sounds. The recognized efficiency of these approaches concerns in particular the timbral quality and the robustness of synthesis facing to parameter variations ([1],[3]). In addition the physical model approach integrates in a natural and efficient way the real time instrumental synthesis with interactive gesture obtained with haptic interfaces ([5][6].

Within this conceptual point of view we were interested to explore instrumental objects configurations in which realistic spatial motion play an important role in the sound generation.

Such configurations are encountered in some simple sounding objects like child rattle, tambourine, maracas, etc. A common feature of these instruments is to present partially self evolving parts in which high frequency vibrating movements are superimposed with larger amplitude slower movements. These intermediate free movements generally result in a fast shaping of the sound as the high temporal density of micro-percussions that characterizes these types of instruments.

The paper describes such rattle model implementation within a particle based physical modeling system CORDIS-ANIMA [3].

The general aim was to reach a consistent multi-sensory simulation with a good balance between the timbre complexity and the auto-generated sound shape complexity in which the spatial configuration may result.

## 2. THE CHILD RATTLE MODEL

A real rattle is made of a gourd provided with a handle and containing a small number of colliding rigid small objects. The sound produced by the percussions of the

inner objects between themselves and against the gourd cavity reveals the complexity of their movements on which the gesture control can be very precise allowing high expressivity. We consider the following features :

- The high temporal repartition density of the shocks due to the low time constant of their motion.
- The possible variation of the tone depending on the localization of impacts.
- The damping or tone altering effect of the inner objects at rest and possible indirect excitation.
- The accuracy of the collisions between objects and cavity that are related to the shape of the objects (punctual fast contacts, sharp vertices, edges or faces contacts)

Moreover, the inner objects interactions although they probably do not produce any direct sound have to be considered as determinant for energy exchanges in the motions, for the inertia accumulation effect in slow movements whose effect against the cavity is probably significant.

Our objective is to preserve these main features while getting some balance between gesture related, acoustical and visual sensitive effects. This goal is particularly significant when there is a small number of inner objects (3 or 4), allowing to implement precise shapes and significant inertia that would make them more gesturally perceptible. The standard physical model based techniques employed in sound synthesis does not include geometrical properties for representing the internal parts of an instrument. On the contrary it is more efficient to consider the model in a functional way and in this case a non-euclidian space motion representation is sufficient. The mains functional part of the gesture to sound chain that are well identified and may be separately optimized are : the exciter that include a non linear effect, the Vibrating Structure (VS) and the sound diffusion system [13].

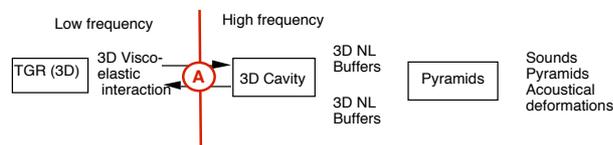
However such approach are not directly applicable due to the impossibility to identify the functional components of the gesture-to-sound chain, as separable parts of the rattle structure. The rattle gourd is both a part of the exciter and of the VS. It also plays the role of the sound diffusion system. The inner objects work as percutors but they are not directly linked to the gesture action.

In addition, the reduction into a 1d functional space applied to the cavity and inner objects would imply a 1dof control gesture that would not to be acceptable since one of the richness of the rattle playing seems to be in the spatial attributes of the gestures.

Indeed Real-time simulation of 1d maracas that has been developed in the past in our laboratory although producing interesting percussion tones this model revealed some weakness when playing it. [8]. Other works on maracas family synthesis although based on physical modeling are more exclusively focused on the sound signal generation [7][18]. As a consequence, the shape and geometrical properties of cavity and inner objects and the ability of the inner objects to interact with each other are determinant in the constitution of dynamic of the percussions and are essential attributes of a real-time playable model.

The figure 1 shows a functional representation of the implemented model.

Small and sharp “pyramids” are moving in a spherical ball. The ball is manipulated by hand through the TGR force feedback transducer [3]. Sounds are produced by the deformations of the pyramids, when they shock the manipulated sphere.



**Figure 1:** Functional representation of the sounding collision model

As an important feature, the sphere is not modelled as a solid 3D object at all, but only by a unique 3D punctual mass, linked to the 3DOF haptic device. The 3D shape around the sphere that can be seen on the screen on figure 3, was only added for visualizing the model, as a final step. Thus, users only manipulate a unique 3D point, and receive all the forces exchanged during the collisions between the sphere and the pyramids through this unique point.

So as the sphere, the pyramids are neither represented as 3D solid objects, but only with a few number of punctual masses (one at each vertex, i.e. four masses) linked through visco-elastic interactions (i.e. 6 interactions). These interactions model the rheological properties of the pyramids’ matter.

The interactions between the sphere and the pyramids, as for them, are 4 collision interactions with visco-elastic buffers. The threshold of the collision buffer codes the minimal distance below which the sphere punctual mass and the punctual masses of each vertex of the pyramid are in contact. Thus, once again, there is no 3D contour for any of the object, nor collision detection on such a contour.

Sound is originated in the high frequency 3D deformations of the pyramids. However, the pyramids simultaneously displace into the sphere, with large 3D displacements of about several centimeters, and oscillate at the acoustical scale superimposed with very small 3D acoustical deformations (about some microns). To extract a 1D acoustical deformation with a null average

value, a mechanism was needed that could not rely on conventional high frequency pass filter.

## 2.1. Sound extraction.

The sound capture needs a projection principle as the audio signal is scalar and the vibratory motion multi-dimensional. An approach which would include sound radiation in a realistic way in the above model would consist in plunging the whole in a propagative medium made of regular net of one D moving masses as a representation of an aerien medium. In this case each cavity mass would have to interact with a set of masses of the propagative net according to its motion and position in the space.

This approach has not been followed further since we do not dispose today of sufficiently efficient techniques to simulate such a propagative net in reasonable conditions in particular a sufficient space resolution for the rfeal time condition.

We introduced a physically based module that maintains the energetic properties of 3D signals, but which extracts the axial (i.e. orientation-independent) relative motions. This module is described with more details in the following paragraph.

## 2.2. Radial projection coupling:LPR.

The LPR is an extension of the interaction element used in the particle interaction physical representation. While the classical interaction element presents a dipolar form (it typically links two particles) the LPR is quadripolar and consists in a pair of internally connected simple dipolar interaction elements called the “link ports” of the LPR. These two ports of the quadripole operate in two separated physical models that may belong to different physical “worlds”.

In the present case such LPR are used to establish a coupling between the previously defined physical world where the rattle with its spatial and geometrical properties is defined and a complementary purely acoustical physical world where only one dimension movements are represented.

The LPR presents two constitutive properties :

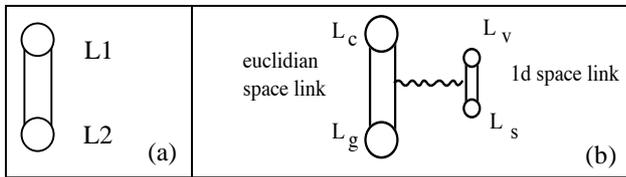
(1) Like the dipolar link interaction element it is characterized by a rheologic property as elasticity, viscosity or non linear law. Formally for each type of dipolar link element defined in the modeling framework it is possible to define a corresponding LPR with the same physical law.

(2) This characteristic rheologic relation is applied to the *sum* of the two axial deformations at each of the two link ports, to produce the corresponding axial forces with a same value at the two ports. This property results in a physical coupling of the two ports that is energy conservative.

In the rattle model, visco-elastic LPRs are used in place of simple visco-elastic links in the vibrating pyramids. The corresponding one D ports of these LPRs are then connected in the one-dimension space to a mass – spring

network that operates as an elementary physical diffusion medium and from which the sound signal is extracted.

The radial projection technique with LPR may be used in a general way to optimize model that present both a spatial complexity and vibrating properties, by reducing to 1d computation some of the vibrating motion generating parts.



**Figure 2.** The <LPR> component (b) compared to a standard link (a).

### 2.3. Multi-rate implementation

The simulation is implemented in a double frequency rate mode on a specialized simulator.[10]. The border between the low frequency computation (3 KHz) and the high frequency computation (48 KHz) was set between the transducer and the sphere' mass, as shown on figure 1. The mass-interaction system inherently allows performing over under sampling on the border, with an energetic coherence [10]. The latency for the gesture side – i.e. the delay between the input and the corresponding output on the transducer, after computation is the smallest possible latency according to the sampling rate – that is 0,33 ms. The latency between the action input and the sound output is constant and equal to 3ms. This last delay is introduced by the output anti-aliasing system. The equivalent sound propagation distance, about 1m, is the maximum limit of ear to source distance in the current manipulation of handled objects.

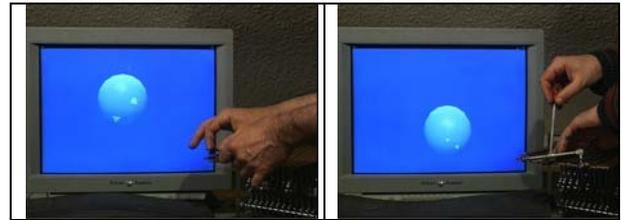
## 3. RESULTS AND COMMENTS.

The two next experiments (figure 3) are both implementation of the child's rattle. The physically-based model used in both cases is exactly the same.

The model allows producing in real time several sounding collision effects, with a relevant force feedback interaction. It features a cooperation between two scales of motion: (1) large and low frequency motions of the manipulation, of the manipulated object and of the macro-movement of the object; (2) small and high frequency motions of the sound deformations in the model. The sounding collisions effects are precisely emerging from the frontier between these scales: large motions are transformed through a non-linearity, in a very short time (i.e. quite instantaneously), in small and rapid motions. During this transformation, energy is transferred from the motion scale to the acoustical scale, but still with energetic coherency.

The two experiments, indeed, only differ in the morphology of the manipulation (figure 3). Within the

first experiment (left on the figure), two independent keys of the transducer [2], that are directly handled, control the two co-ordinates (x, y) of the manipulated sphere. These keys move both vertically, along the same axis. Consequently, the manipulation is non-usual. The motion of the manipulation is very different from the visual motion of the sphere on the screen. On the contrary, within the second experiment (right on figure 3), the manipulation is performed through a 2D stick [11]. The motion of manipulation is similar to the visual motion of the sphere on the screen.



**Figure 3.** The child's rattle: two ergonomies for the manipulation.

However, undoubtedly, users find it very realist and believable. In all the case, during long playing performances, with a lot of players (more than 100), all of the experimenters perform accurate manipulation of the ball and of the pyramids. Moreover, players do not remark the difference of the manipulation - non-natural on the left, natural on the right of the figure 3. They do not pick out any noticeable discomfort in the "non-natural" manipulation on the left, and did not report any preference for manipulation on the right. More surprisingly, in the left situation, the manipulation is more accurate than with the second (right) with usual morphology. Indeed, persons were in that case particularly efficient in controlling accurately the shocks of the pyramids on the ball, producing expected auditory rhythmic sequences as percussionists do.

In order to exemplify the drastic importance of both the force feedback and of the quantitative requirements for the quality of the hand-to ear chain, we experimented two ways of degrading performances of the system: removing the force feedback and increasing the latency.

When removing the force feedback, the first manipulation shown on the left part of the figure 3 becomes absolutely ineffective, as in those drawing boards with which children are drawing by means of two independent knobs. The motion of the pyramids becomes completely uncontrollable, and the sound collisions become chaotic.

When increasing the latency between action inputs and sensorial outputs, the perceptual association between softer haptically and visually inferred collisions, and hard percussive auditory events becomes progressively less and less relevant. This finally lead the user to split the scene in two parts: a visual and haptic part, and a

more and more arbitrarily superimposed auditory outputs. Such dissociation is revealed by the loss in the organization of sounds, such as rhythms, which indicates that users play more with the visual 3D large displacements than with the temporal properties of the sounds. In addition, in the case of the smallest possible hits with the lowest auditory level and the lowest tactilo-kinesthetic sensation, such dissociation leads to a loss of the haptic feeling of the force. This basically means that the role of the sound is essential in the identification of a collision, as a media that encodes the energy of the percussion.

#### 4. ACKNOWLEDGEMENTS

This work has been supported by the French Ministry of Culture and by the FP6 Network of Excellence IST-2002-002114 - Enactive Interfaces.

#### 5. CONCLUSION

The goal of this physical modeling and multisensory simulation was to investigate the domain of some simple sounding rattle that present both spatial properties and low time constants vibrating properties.

Two types of tasks were achieved in this work.

Firstly the rattle model although simple if only considered according to its sounding properties, becomes complex when one must reproduce coherently its gestural, spatial and acoustical effects. To achieve this goal we introduced some optimization in a particle based physical model that allows to treat separately the spatial and the vibrating properties while respecting the energetic consistency of the gesture to sound chain.

From this simulation we have shown the importance of the force reaction in the control gesture and in the same way we have experimentally evaluated the effect of the gesture to sound latency.

The rattle example shows that haptics interfaces and physical modeling promise a much better sensibility and expressivity of our digital instruments - hopefully comparable to those of the acoustic instruments.

However, as pointed in the article, implementing such relations requires a drastic quality in the dynamics.

#### 6. REFERENCES

- [1] Cadoz C., Luciani A., Florens J.L.. "Responsive Input Devices and Sound Synthesis by Simulation of Instrumental Mechanisms: The Cordis System". *Computer Music Journal*, Vol. 8, N°3, pp. 60-73. M.I.T. Press, Cambridge Mass. 1984.
- [2] Cadoz C., Lisowski L., Florens J. L., "Modular feedback keyboard", *Computer Music Journal* Vol 14 N°2 MIT Press. 1990.
- [3] Cadoz, C. Luciani, A. Florens, J.L."CORDIS-ANIMA : a Modeling and Simulation System for Sound and Image Synthesis- The General Formalism", *Computer Music Journal*, Vol 17-1, MIT Press. 1993
- [4] Cadoz, C. "Le geste, canal de communication Homme / Machine : La communication instrumentale", in *Special Issue of Interfaces Homme/Machine*, Hermès Ed, Vol. 13 N°1, 1994.
- [5] Cadoz C., Wanderley M. (2000). "Gesture-Music" - in "Trends in Gestural Control of Music", M. Wanderley and M. Battier, eds, pp. 71-94 -©2000,
- [6] Castagné N, Cadoz C, Florens JL, Luciani A: "haptics in Computer Music: a Paradigm Shift" *Proc. of Eurohaptics* Munich, 2004, pp422-425.
- [7] Cook, P., "Physically Informed Sonic Modeling (Phism): Synthesis of Percussive Sounds", *Computer Music Journal* Vol 19, MIT Press, Cambridge, Mass, U.S.A., pp 38-49. 1996
- [8] Florens JL, Cadoz C, Luciani A. "Optimized realtime simulation of objects for musical synthesis and animated images synthesis". ICMC 1986
- [9] Florens JL Cadoz C.. "Modèles et simulation en temps réel de corde frottée". *Colloque de physique / Colloque C2*, supplément au n2 tome 51. pp 873-876. 1er CFA Ed. De Physique. Paris.1990.
- [10] Florens, J., Cadoz, C., Luciani, A., A real-time workstation for physical model of multi-sensorial and gesturally controlled instrument, ICMC 98, 1998 (1998) pp.8 pages
- [11] Florens JL. "Real time Bowed String Synthesis with Force Feedback Gesture". Invited paper. Forum Acousticum. Sevilla. November 2002.
- [12] Gillespie B. "The Virtual Piano Action: Design and Implementation" *Proc. of the International Computer Music Conference*, Aarhus, Denmark, Sept 12-17., pp. 167-170. 1994.
- [13] Incerti E, Cadoz C "Topology, Geometry, Matter of Vibrating Structures Simulated with CORDIS-ANIMA Sound Synthesis Methods"- *Proc. of International Computer Music Conference - Banff Canada*, , pp 96-103 MIT Press 1995
- [14] Luciani A. "Dynamics as a common criterion to enhance the sense of Presence in Virtual environments". in *Presence* 2004. Valencia. Spain, oct 2004
- [15] Nichols C: "the vBow: a Virtual Violin Bow Controller for Mapping Gesture to Synthesis with Haptic Feedback" - in *Organised Sounds* - Leigh Landy ed. - Leicester, United Kingdom, 2002.
- [16] Rimell S, Howard D M., Tyrrell A M., Kirk R, Hunt A - "Cymatic: Restoring the Physical Manifestation of Digital Sound using Haptic Interfaces to Control a New Computer Based Musical Instrument" - *Proc of Int. Computer Music Conference*, Göteborg Sweden, 2002.
- [17] Rochesso D, "From musical acoustics to everyday acoustics: a physical modeling route". *Invit. paper Proc. of the Stockholm Music Acoustics Conf.*, 2003.
- [18] Rath M, Rochesso D, and Avanzini F. "Physically based real-time modeling of contact sounds" *In International Computer Music Conference*, Göteborg, Sweden, 2002.