PRODUCTION OF IMMERSIVE MUSICAL ARCHITECTURES BY PHYSICAL MODELLING OF SELF-SUSTAINED OSCILLATING STRUCTURES

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ABSTRACT

This paper presents the first results of a study on physical modelling of self-sustained oscillating structures, that was carried out with the sound synthesis and musical creation environment GENESIS. This study aims at producing sounds with rich timbre and, at a compositional level, at building immersive complex musical architectures. Indeed, based on the mass-interaction CORDIS-ANIMA physical modelling formalism, GENESIS has got the noteworthy property that it allows to work both on sound itself and on musical composition in a single coherent environment. So generic tools to model self-sustained oscillating structures are developed and analysed in order to work on rich timbres and on the temporal macrostructure of the music, that is of the gesture and the instrumental performance, as well as the composition. In fact, we use the complex motion of a bowed macrostructure as a musical events generator which behaviour may simulate an expressive "instrumental performance" and lead to evocative and immersive musical architectures.

1. INTRODUCTION

The aim of sound synthesis by physical modelling is the search of a naturalness of synthesized sounds. It is thus logical to work not on the sound itself, but on what produces this sound, that is the physical object which is able to vibrate at acoustical frequencies. Indeed, human's ear was built by evolution for a precise purpose: to give us information about our environment. So, it is very sensitive to sounds (musical or not) produced by a well-determined physical cause. Consequently, sound synthesis by physical modelling will tend to produce evocative sounds.

But in music, what is physical is not only the sound produced by real instruments but also the instrumentalist's performance. Hence the use of physical modelling only to produce sounds with realistic timbre is a little restrictive. Using the physical modelling we can try to model also the instrumentalist itself, or at least some of its physical behaviour. This leads to an approach of the sound construction at the scale of the musical macrostructure and, then, offers a way to work at the compositional level.

GENESIS [7], a software based on mass-interaction physical modelling, takes this idea into account by proposing an environment where we can build objects that move at acoustical frequencies as well as at gesture frequencies (more generally at macrotemporal frequencies). As a result, within this environment, the arbitrary boundary between the timbre, the composition and the perfomance tends to be erased.

Among the infinite variety of physical models the environment allows to build, the specific category of self-sustained oscillating structures is particularly interesting. Indeed they allow to produce rich timbres but also, when used at low (gestural) frequencies, complex movements that can support rich expressivity. This article presents a study on this category of physical models which aims in developing simple models of, for example, violin, clarinet or oboe in the GENESIS environment and to find the relevant parameters of these models that can be used for rich timbre sound synthesis or for complex musical architectures creation.

2. PHYSICAL MODELLING WITH GENESIS

2.1. The theoretical basis of GENESIS: CORDIS-ANIMA

GENESIS is a coherent environment used for sound synthesis and more generally music creation. It is based on an axiomatic mass-interaction formalism called CORDIS-ANIMA [6]. Every object built with this formalism is constituted of different modules communicating with each other. We can distinguish two types of modules: <MAT> modules representing material points that for example may be provided with inertia, and <LIA> modules linking two <MAT> modules and representing the interactions between them (stiffness, viscous friction…). The two main <MAT> modules used in GENESIS are the SOL (fixed point) and the MAS (ideal inertia). The main linear <LIA> modules used in GENESIS are the RES (stiffness[1]), the FRO (viscous friction[2]) and the REF (viscoelastic link). There are also non-linear modules called BUT[3] and

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[1] We call K the characteristic stiffness coefficient.

[2] We call Z the characteristic viscosity coefficient.

[3] The BUT is a viscoelastic conditional link, that is to say, a viscoelastic link which is effective if the difference between the positions of the two <MAT> elements that it links is under a given threshold. This module is often used for collision simulation.

LNL[4]. So, thanks to the CORDIS-ANIMA language, we can build an infinite variety of mass-interaction networks that correspond in a certain way to a space and time discrete view of Newton's laws. The main advantage with this coherent modular language is that everything is modelled with the same tools (the elementary modules and the laws of their combinations), ensuring the consistency of every model. Furthermore, it is very simple to build interactions between two models developed with CORDIS-ANIMA, since they can be done as interactions between two elementary <MAT> modules. Hence, it is possible to create complex models that are composed of many elements (for example the model of a string or of a pipe…) and simply make them interact by means of one or several <LIA> modules.

2.2. The Instrumentarium

In parallel to the GENESIS models development, a library of these models, called the *Instrumentarium*, has been built in order to compare and classify them according to an accurate conceptual organization. Analysing various models, fundamental functions and features have been identified, isolated and used as a classification basis. The aim of this library is to define generic models or modelling techniques that could be easily used by GENESIS users, whether he or she is a composer or for example a pedagogue who wants to use GENESIS as a support for his or her teaching in Newton's mechanics. Consequently it is very important to take this into account during the development of our models in order to prefer generic models to ones that use ad-hoc functions.

2.3. The study of self-sustained oscillating structures

Many studies were carried out about physical modelling of self-sustained oscillations of musical instruments with the aim of digital synthesis of real sounds. For example the digital waveguide physical modelling technique was used by Smith, Cook and Scavone to synthesise woodwind, bowed string [13] and singing voice sounds [8], or by Karjalainen and Välimäki to model wind instrument bores [14]. The modal synthesis [1] is also a good way to produce this kind of sound.

In the domain of musical acoustics, many researches were undertaken on self-sustained oscillations of musical instruments, which are a good basis for physical modelling in computer music. One can quote inter alia the names of Benade [2] [3] [4] for woodwind instruments or Cremer [9] for bowed strings.

The study presented in this paper, which aims at providing self-sustained oscillations instrument models in the GENESIS *Instrumentarium*, uses many results obtained by musical acousticians. That is why simple models of bowed strings or woodwinds are presented below, but it is important to notice that our goal is not to model a specific real instrument in the most accurate way but to develop tools that are generic for self-sustained oscillating structures modelling.

3. RESEARCH ON BOWED STRUCTURES

3.1. A bowed simple vibrating structure

One of the most studied families of instruments is the bowed strings. Thus we will first study the bowing of a vibrating structure in the GENESIS environment. As for all self-sustained oscillations instruments, there is a non-linear element in the instrumental chain of the bowed strings that ensures the production of a high frequency oscillation (vibration of the string) from very low frequency behaviour (movement of the bow). This is the non-linear interaction that takes place between the rosin on hair of the bow and the string. We can see its shape on the graph below and how it is modeled in the LNL window of GENESIS:

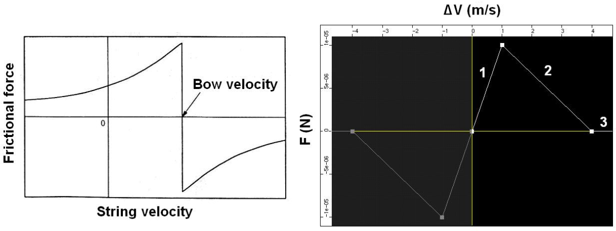

Figure 1. Left: frictional force as a function of the string velocity for a bowed string. After Fletcher and Rossing, 1998 [10]. Right: frictional force as modelled in the LNL window of GENESIS.

This simplified curve that models the interaction between the bow and the string is sufficient to work with, and we will see that it leads to phenomena that are characteristic of real bowed strings behaviours. But the aim is also to use this interaction with other structures than a modelled string. The method used is to analyse the behaviour of a bowed basic oscillator and to generalize to more complex ones. We can see on figure 2 (left) the representation of the model as it appears on the graphical interface of GENESIS[5]. The MAS module called M_A represents the bow inertia and the structure called OSC, which contains a SOL (S), a MAS (M) and a REF module, is a damped harmonic oscillator that M_A will bow via the LNL link. The figure 2 (right) shows a string modelled as a chain of MAS linked with REF modules. This structure is bowed via the same LNL module.

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[4] The <LIA> module called LNL let us draw the interaction between two <MAT> by means of a function F(ΔX) or F(ΔV), with F the output force, ΔX and ΔV respectively the difference between positions or velocities of the two linked <MAT>. The user can draw every one-variable function he wants.

[5] It is important to keep in mind that the representation plan is not a metric space but a topologic one. That is to say, only the links between <MAT> elements will influence the behaviour of our model, not how the <MAT> elements are placed on this plan. Furthermore, the <MAT> modules can move along the axis perpendicular to this plan and only along this axis. That is why GENESIS is called a one-dimension simulation environment. But it is generally not a problem for sound synthesis, since oscillations develop themselves mainly on a single axis and it is possible to take into account two or three dimensions effects via LNL links or judicious use of modularity.

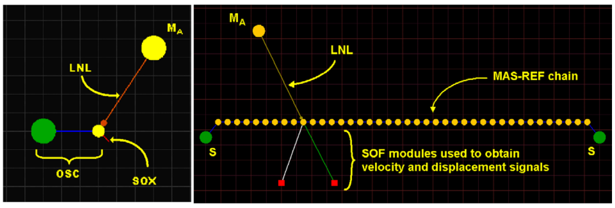

Figure 2. Left: model of a bowed basic structure. Right: model of a bowed string. SOF and SOX modules (respectively force and displacement output) are used to “hear” a structure vibrating.

We can separate half of the symmetrical friction curve into three parts, noted 1-3 on figure 1 (right). The first one is called the “sticking zone” and the second one the “sliding zone”. For a real bow, the slope of the sticking zone is almost infinite (cf. figure 1, left) but if we use such a characteristic, the value of the equivalent viscosity Z (i.e. the value of the slope) is almost infinite too. That is why we must use a finite slope unless the algorithm diverges when the difference of velocity is such as the operating point is in the sticking zone of the curve, leading to a sound with more or less white noise (that nevertheless can get a certain interest). Furthermore, as McIntyre, Schumacher and Woodhouse say in [11] the finite slope of the sticking zone can partially take into account the effects of torsional waves along the string.

Moreover, we must take into account the particularity of our model of interaction. Indeed, the part 3 of the curve corresponds to a zero force and the slope of the part 1 is finite, which is not the case for the real characteristic. The analysis of the bowed simple oscillator behaviour leads to two general conclusions: firstly, the bow velocity value must be included between the two boundaries of the sliding zone to obtain a self-sustained oscillation. Indeed, if the velocity is in the third part, no force is applied on the oscillator, and if it is in the first part, no sliding friction can occur since the operating point will be always in a Z positive part of the characteristic. Secondly, the absolute value of the sliding zone slope (noted Z_{neg}) must be higher than the positive damping (Z_{pos}) of the vibrating structure in order to obtain self-sustained oscillations[6]. If these two conditions are met, a self-sustained oscillation occurs as we can see on figure 3. This fact is due to the negative slope of the curve in the sliding zone. We can see on the velocity signal, for each period, when the operating point passes from the sticking zone to the sliding one (inflexion point). One can note that before this inflexion point, we can see a damped oscillator behaviour (exponential decrease of the velocity). After this point, the velocity increases drastically because of the sliding friction; this leads to oscillations.

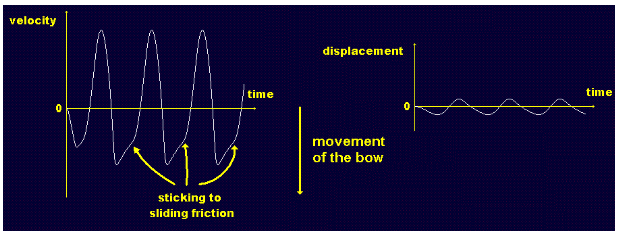

Figure 3. Velocity and displacement signals for the bowed oscillator described on figure 2 (left), with a bow velocity in the sliding zone of the LNL characteristic.

If we give the correct values to the parameters that we spoke about in the simple oscillator study, the bowing of the string modeled in figure 2 (right) leads to the well-known Helmholtz motion of the string as we can see on figure 4.

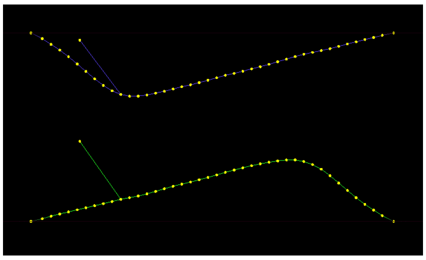

Figure 4. The Helmholtz motion of the string at two moments which have got a difference in phase of a half period. The bow is moving up at a constant velocity.

Moreover, displacement and velocity signals of our chain are comparable to experimental measures on real bowed strings (cf. figure 5).

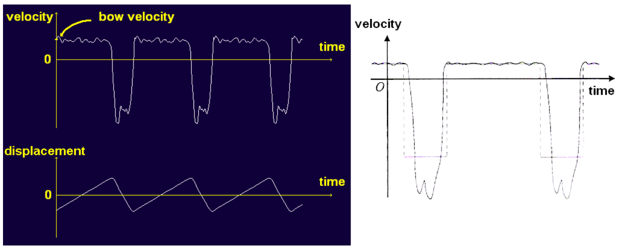

Figure 5. Left: velocity and displacement signals at the bowing point, for our string model. The bowing point is at a quarter of the string. Right: velocity of a real string at the bowing point. After Boutillon, 2000 [5].

So, the simplified friction characteristic used in our model is sufficient to obtain realistic behaviours and moreover to get plausible bowed string sounds. Note that the real friction force does not tend to zero when the difference between the bow velocity and the string one is high, whereas it does in our model. The aim is to be able to produce particular gestures like a bow that ends without the bow on the string (in order to be able to produce the sound of the free motion of a string after bowing). Indeed, if we want to cut the link between the vibrating structure and the MAS M_A, we just need to accelerate it until the operating point is always in the third part of the friction characteristic.

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[6] Furthermore, if the absolute value of Z_{neg} is higher than Z_{pos} but if these two values are comparable, the transient is very long with a percussive attack at its start. So to quickly obtain a self-sustained oscillations regime, $|Z_{neg}|$ must be much higher than Z_{pos}.

So the LNL link described in this part can be used to bow many different structures such as strings, bars, membranes… But as we will see below, this LNL link may be relevant for woodwind instruments modelling too. This leads to a generic approach of self-sustained instruments of different physical natures such as bowed strings and woodwinds.

3.2. A particular bowed structure

Now, if we take our previously developed string model and link only one of its extremities to a SOL module, the produced sound when we bow the free extremity (using the same LNL as above) sounds like a clarinet. In order to explain this, we can analyse the non-linear characteristic of a woodwind reed (cf. figure 6). It represents the volume flow through the reed as a function of the difference of pressure between the player's mouth and the reed. A remarkable fact is that the friction characteristic of the LNL module developed previously can easily approximate the shape of the curve above, with the help of an analogy that we explain below.

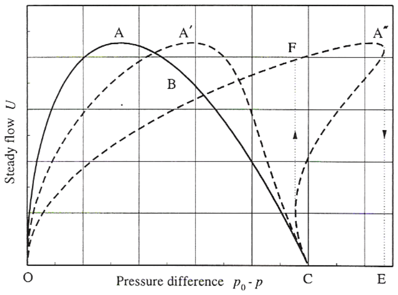


Figure 6. Characteristic of volume flow as a function of pressure difference for a woodwind single reed (OABC curve) and a woodwind double reed (one of the three curves, according to the reed channel resistance). After Wijnands and Hirschberg, 1995 [15].

The analogies between mechanical systems and aeroacoustical ones are well known and have been developed in many acoustics books [12]. First of all, the comparison between our LNL characteristic and the curve above suggests that the force applied on and the velocity of the MAS module are respectively the analogue of the volume flow and the pressure inside the reed. But in order to be more precise, let us consider two fluid tanks at different pressures P1 and P2, connected by a channel where a volume flow U of fluid circulates. According to the Euler's equation, we have got in this case:

$$\rho\frac{dv}{dt} = -\frac{dp}{dx} \Rightarrow \Delta P = P1 - P2 = \frac{L\rho}{S}\frac{dU}{dt}, \qquad (1)$$

with L and S respectively the length and the section of the channel, v the speed of the fluid particles and ρ its density. One often calls the factor Lρ/S the acoustic mass. The equation connecting the pressure difference between the two tanks and the volume flow is similar to the one connecting the speed difference between two masses connected by a spring:

$$\Delta v = \frac{1}{k}\frac{dF}{dt}, \qquad (2)$$

with Δv the speed difference between the two masses, K the stiffness coefficient of the spring and F the modulus of the force applied on the two masses. One can then carry out the analogies gathered in the following table:

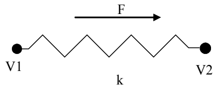
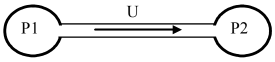
Mechanical system	Aeroacoustical system
	
$\Delta v = \frac{1}{k}\frac{dF}{dt}$	$\Delta P = \frac{L\rho}{S}\frac{dw}{dt}$
F	U
v	P
1/k	Lρ/S = M_a

Table 1. Analogies between mechanical and aeroacoustical systems.

These analogies let us develop easily woodwind instruments models with mass-spring networks. Indeed, just as our strings are modelled by a succession of masses connected by springs, the body of the wind instruments can be seen as a succession of tanks connected by cylindrical channels.

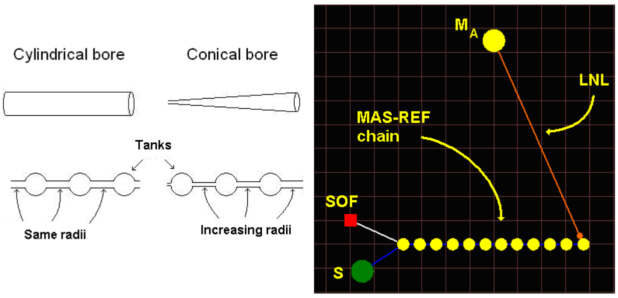


Figure 7. Left: simple models of cylindrical and conical bores for wind instruments. In the second case, on the right, the channels have increasing *radii* in order to model the widening of the bore. Right: woodwind as modelled in GENESIS. The non-linear characteristic used is the same than for the bowed string.

So, one can translate now this schematised aeroacoustical model into a mass-spring system by means of the developed analogies. On the figure 7 (right), we can see the GENESIS model that can be used for woodwind sound synthesis. The mass-spring chain is bowed at its free extremity, that is to say, where the v/F ratio is the highest. This is coherent with the behaviour of woodwind instruments for which the P/U ratio is the highest at the reed. On the contrary, a fixed point will represent a hole in the bore. So the SOL at the left extremity represents the hole of the bell. It is possible to model the tone holes too, by adding SOL modules linked to masses along the chain.

As we said above, it sounds like a clarinet for a homogeneous mass-spring chain. This is understandable since the clarinet has got a cylindrical bore. Thus, it might be interesting to try to model other bores, for example a conical one, to obtain oboe-like sounds. The section of the bore of the oboe increases like the square of the distance to the mouth (since its diameter is proportional to the latter). The analogue of the section S is the constant of elasticity K (with a constant factor Lρ). Thus, by giving values, according to a parabolic law, to the K parameters of the consecutive REF modules, it is possible to obtain oboe-like sounds.

On the figure below, it is possible to compare the spectra of the sounds obtained for the homogeneous string model (called CLARINET) and the non-homogeneous one (called OBWA) to experimental data taken in [10]. It is also possible to compare these with the results given in the chapter 21 of [2].

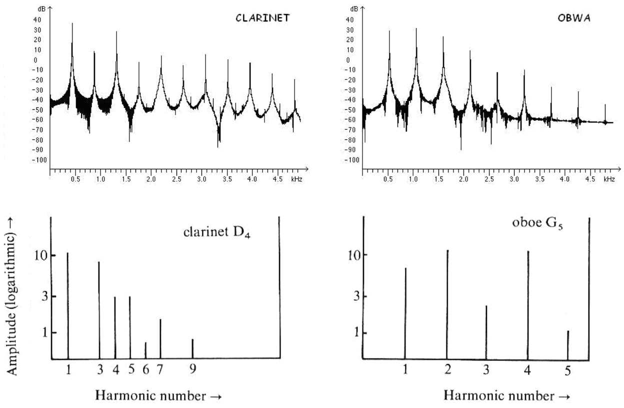


Figure 8. Spectra of the sounds that we obtained with the CLARINET and OBWA models and comparison with experimental data on real woodwinds. After Fletcher and Rossing 1998 [10].

So, as for the real instruments, the fundamental prevails for the CLARINET whereas the second harmonic does for the OBWA.

Furthermore, as for a real clarinet, the sound obtained with our CLARINET model has got prevalent odd-numbered harmonics. Even-numbered harmonics are not absent of the spectrum, which has been explained in different references [2] [4].

The analogies developed in this part are very useful since an air column will be simply modelled by the same modules than a string. So it will be very easy to couple structures like strings or membranes with a tube: we only need a <LIA> module. Thus, one can hear for example an oscillating structure vibrating through a duct that has got vocal formants in order to produce vocalizing sounds. This example illustrates the coherence of CORDIS-ANIMA as a general formalism; there is no need to deal with the compatibility of the different models that we develop since the language itself ensures the compatibility.

4. A NEW WAY OF COMPOSING MUSIC: THE BOWING OF MACROSTRUCTURES

In this last section we use the bowed structures behaviour in order to work at the composition level. Indeed, by using bowed macrostructures we can develop features and tools in the GENESIS environment, that enable to create events at macrotemporal (compositional and instrumentalist performance) scale. The “macrostructure” term is used to speak about structures that can vibrate at very low frequencies and so that can model the instrumentalist’s gestures. The underlying idea is that everything that has got inertia is modelled by a MAS module in GENESIS. Consequently, the MAS module, used to model the excitation of a vibroacoustical structure (such as a bow or a plectrum) can itself be a part of a vibrating macrostructure, which can lead to a complex movement of our excitator.

4.1. A bowed “macrostring”

If we consider a bowed string, as in the third session above, but with a low frequency fundamental mode (~1Hz), and if different MAS modules of this string are used to interact with vibroacoustical structures, it is possible to simulate a complex performance with this macrostructure. On the figure below, we can see such a model, with a bowed “macrostring” that contains plectra, as it has been built in GENESIS.

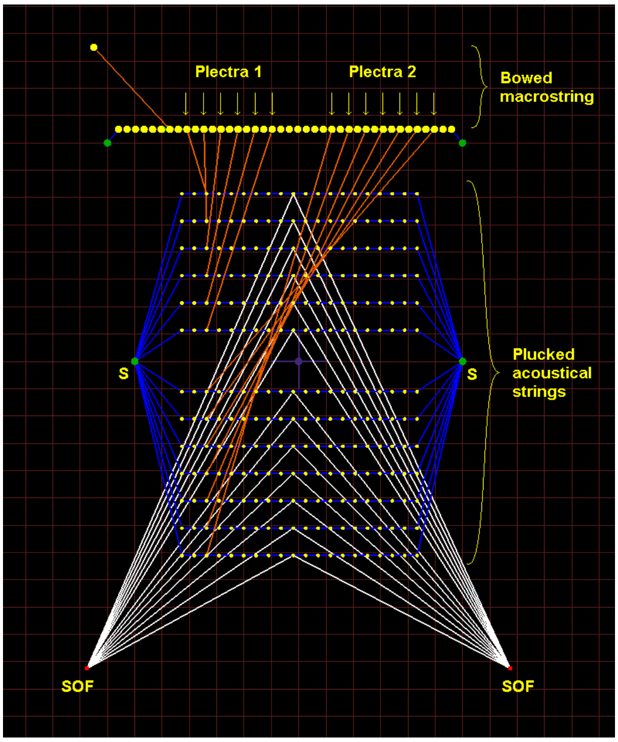


Figure 9. Model implying a “macrostring” which contains thirteen plectra playing on different acoustical strings.

The model, as it appears on figure 9 has been conceived in order to produce a particular play going from low to high acoustical frequencies. Indeed, from top to bottom, the thirteen acoustical strings’ fundamental frequency increases. So we have separated these into two groups, each one plucked by a type of plectra (1: low frequency strings, 2: high frequency strings). The first type of plectra corresponds to a LNL module which is calibrated to obtain plucking when the MAS modules of the “macrostring” are at a precise negative altitude “x=-a” (the acoustical strings are in the “x=0” plan), which is an altitude reached by the “macrostring” during its motion (cf. figure 10). The second type of plectra is calibrated to pluck when the MAS modules reach the “x=0” plan. Figure 10 and 11 show the advantage of working with two plectra groups, since what we can see is a movement between two plans[7]. So the “instrumental play” has got a repeated cycle that is divided into two phases: the first when the “macrostring” is at its negative altitude (figure 10) and the low frequency strings are plucked, the second when it is at the zero altitude and the other strings are plucked.

4.2. Waves and rains of plectra: immersive musical architectures.

The “instrumental performance” produced is a periodic alternation between complex series of low and high-pitched notes. Furthermore, these musical events evolve in time since the behaviour of the “macrostring” described above is the transient one. Progressively, higher amplitude oscillations take place, and it results in less plucks (but more disorganised). This gives the impression to pass from a vigorous part with lots of musical events to calm and quietness.

Due to its physical origin, the musical architecture obtained is strongly immersive and has a strong evocative capacity. Indeed, according to the acoustical strings damping (or more generally acoustical structures damping) and the macrostring oscillation frequency, the sensed musical events can be in the cognitive domain of rain, fall of water drops, running water or waves breaking on a beach. This is not surprising since the mechanism used - that is propagation of waves along a string - has analogies with the propagation of surface gravity waves in a sea. So, the musical architecture resulting of the macrostring behaviour leads to immersive sound environment with musical events that may have an aqueous characteristic.

Finally, concerning the temporal distribution of the musical events, the bowed “macrostring” produces an “instrumental play” that is not precisely predictable but, so far, not unpredictable either. Its periodic oscillation leads to a pulsation. Moreover the precise analysis of the model’s behaviour can give information on how to use it, to privilege statistically a precise note for example.

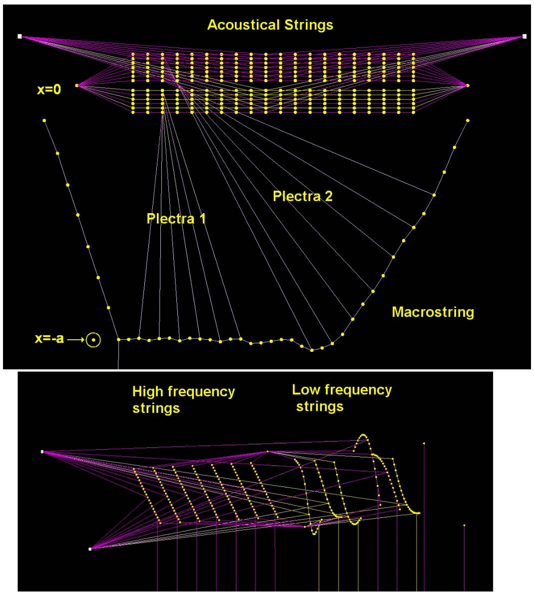


Figure 10. Two different viewpoints of the simulation of the model shown on figure 9 at 1,25 second. First phase of the period of the “macrostring” movement. This one goes down until it reaches an altitude located by the MAS circled (top picture). The six plectra on left are calibrated to pluck the low frequency strings at this altitude. So we can see on the bottom picture that these six strings oscillate. On this picture, the vertical scale is much lower than for the top picture.

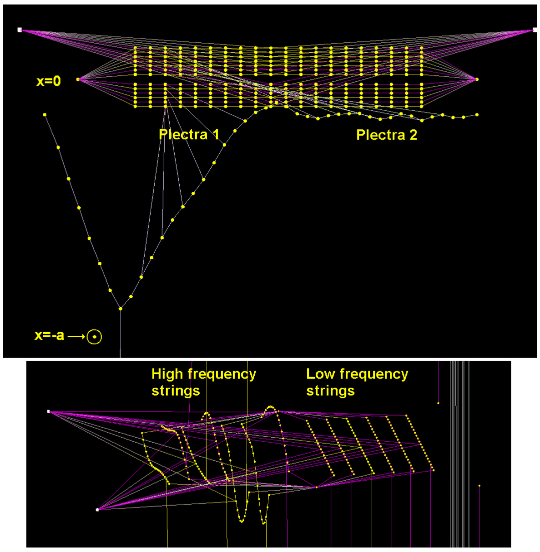


Figure 11. Two viewpoints of the simulation of the model shown on figure 9 at 2,5 seconds. Second phase of the period of the “macrostring” movement. This one goes up until it reaches the “x=0” plan. Now the seven plectra of the second group pluck the high frequency strings as we can verify it on the bottom picture.

Furthermore it has got very rich possibilities. For instance, it is possible to change the period of the “instrumental play” by changing the “macrostring” fundamental frequency or to increase or decrease its transient by influencing the bow’s friction characteristic. It is possible to change the acoustical strings damping in order to get more or less resonant sounds, or to bow these ones instead of plucking

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[7] The string behaviour is typical of a bowed string transient. But for this system, this one is very long because of the very low frequency of the string oscillation.

them… By varying all these parameters, it is possible to travel, with the different musical architectures obtained, in various cognitive domains.

4.3. The role of excitation and vibroacoustical structure

A macrostructure with a complex behaviour is not sufficient to obtain a rich “instrumentalist like” model. One must work also on the type of excitation and on the vibroacoustical structure. Indeed, the bowed macrostring used in the previous part can lead to a particular complex “instrumental play” with the plectra described but a completely different one with bows for example. This is due to the displacement dependence of the plectrum interaction, and the velocity dependence of the bow one. Thus, the type of excitation will reveal differently our macrostructure behaviour. That is why we call the latter a “potential events generator” since it must be connected to vibroacoustical structures with appropriate links to obtain particular musical events.

Furthermore, different vibroacoustical structures will reveal more or less the complexity of the potential events generator behaviour. For example, the plectra dynamic has little influence on the behaviour of the acoustical strings used in the previous part. If we make possible a contact between the strings during their movement, we can obtain a totally different vibroacoustical structure which behaviour depends strongly on plectra dynamic. By connecting our different acoustical strings with BUT modules (see 2.1) with appropriate thresholds, they will be free for low amplitude movements but not for large amplitude ones. So according to the hardness of the plucks (related to the plectra velocity), they will collide or not. At the beginning, the plucks will lead to lots of collisions but progressively, as the amplitude of the macrostring increases, collisions will more and more seldom occur and finally there only will remain plucked strings that oscillate freely. So, this vibroacoustical structure will clearly reveal the macrostring behaviour evolution via the musical events timbre.

4.4. Potential events generator analysis

As said previously, the potential events generator described here was built with global considerations on its possible behaviour. By using this technique for music composition, the aim is not to describe, like with a score, which musical event must occur at one precise moment, but to make complex musical architectures emerge from global and statistical considerations. Of course the analysis of these musical architectures must be very precise in order to improve understanding of our potential events generator behaviour and to know what are the pertinent parameters that influence particular characteristics of this behaviour. According to what we said in the previous parts, the type of excitation and the vibroacoustical structure characteristic response to this excitation has a main role in the production of particular musical patterns or timbres. For example if we consider the example developed, it is necessary to work on displacement signals of the different plectra inserted in the macrostring since the plectrum-type interaction is a non-linear one that depends on position difference between two <MAT> modules. More precisely, it is an elastic interaction that takes place in a finite zone which length is L. On the figure 12 (up) is shown the displacement signal of a plectrum inserted in the previous model macrostring for the first seconds of simulation. There is an interaction when the plectrum has got more or less an altitude comprised between x=0 and x=L, according to the deviation calculated resulting of the vibroacoustical string vibration amplitude. We can see on the figure 12 the intersection (in bold) between the zone of interaction and the temporal signal, which shows when and how the acoustical string is plucked. “Indents” on both sides of “plucking zones” show their maximum possible deviation.

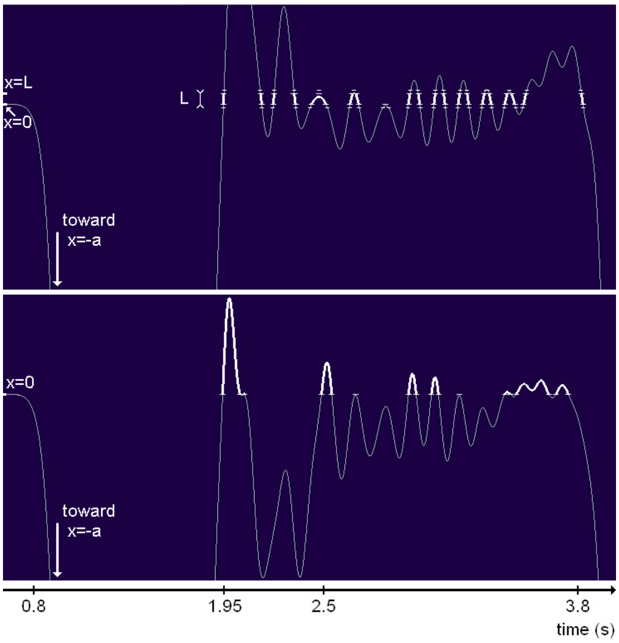

Figure 12. Displacement signal of a MAS module inserted in a bowed macrostring and which is linked by a plectrum-like interaction to an acoustical string. Up, the plectrum length L is small. Down, it is big.

As we can see on figure 12 (up), plucks won’t be identical. For example, the first four plucks are well determined whereas the fifth (at 2.5 seconds of simulation) corresponds to a plectrum that grips slowly the string but do not release it immediately. This leads to a sound with a “sliding fundamental”, since the string vibrates with a smaller length when it is hold by the plectrum. On figure 12 (down) the plectrum length is much bigger, which leads to soft percussive sounds, with “sliding fundamentals” too.

We can see also on figure 12 a change of behaviour of the macrostring due to the interaction with the vibroacoustical structure. Indeed, long plectra will lead to stronger interactions with acoustical strings and a bigger change of the macrostring behaviour, whereas in the case of small plectra, the displacement signal is almost the same as for a macrostring without interaction with acoustical structures. So, even if we are able to accurately describe, repectively the macrostring behaviour alone or the acoustical structure one, it may be very difficult in some cases to foresee what will be the coupled system behaviour. It is for example the case for long plectra in the system above. But it may nevertheless be interesting to use this kind of plectra: whereas with small plectra, macrostring permanent oscillation regime will rapidly occur, leading then to a repetitive pattern, it will be very hard to obtain with long plectra, leading to a rich and evolving "instrumental play".

Finally, it is possible to have a visual representation of the "instrumental play" resulting of the potential events generator behaviour, by using displacement signals of the different plectra of the macrostring. It is possible to organise these (for example ones above the others according to pitches, timbre characteristics, etc…) in order to create a kind of staff or score where we can see the repartition of musical events in time and how they are "interpreted" according to the shape of the displacement signal. Of course, this approach is generic; it can be used for every models where we can separate vibroacoustical structures from potential events generators and linked to these with interactions defined in displacement or velocity space.

4.5. Conclusion of this part

As a conclusion, the composition with GENESIS corresponds to a different approach than the "classical" one. Indeed, in this environment, everything is modelled with physical mass-interaction networks and the arbitrary boundary between the timbre, the composition and the "perfomance" tends to be erased: for example one changed parameter of the vibroacoustical structure can have an influence on these three levels of music creation. Finally, one must study in details these sorts of models because in one hand they have got rich possibilities but in the other hand one must wonder: what are the minimum characteristics required to get a relevant "instrumentalist like" model? There is no doubt that the research on this point with GENESIS is at its infant. But it is an important question and it will be certainly fruitful to carry out deeper researches in this way.

5. CONCLUSION

Self-sustained oscillating structures category is a very useful family of models that is relevant for studies upon both timbre and composition in GENESIS. By means of analogies, real musical instruments of different natures can be simply modelled by almost the same bowed structure. Moreover, GENESIS environment ensures the compatibility of all the models developed, since the same elementary modules are used for the building of all structures. It is thus possible to couple easily different vibroacoustical structures in order to build complex networks, leading to interesting timbres.

As for the composition in GENESIS, bowed macrostructures offer many possibilities that can lead to various immersive musical architectures, but need to be deeply analysed in order to be used in the most possible precise way. By using appropriate displacement or velocity signals, it is possible to have a visual representation of the musical architecture. It can give us a better comprehension of this kind of tools, which is necessary in order to use these in a musical piece.

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