SONIK SPRING

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ABSTRACT

This paper presents a new digital musical instrument that focuses on the issue of *feedback* in interface design as a condition to achieve a highly responsive and highly expressive performance tool. The Sonik Spring emphasizes the relationship between kinesthetic feedback and sound production while linking visual and gestural motion to the auditory experience and musical outcome. The interface consists of a 15-inch spring that is held and controlled using both hands. The spring exhibits unique stiffness and flexibility characteristics that allow many degrees of variation of its shape and length. The design of the instrument is described and its unique features discussed. Three distinct performance modes are also detailed highlighting the instrument's expressive potential and wide range functionality.

Keywords
Kinesthetic and visual feedback. Gestural control of sound. Interface for Sound and Music.

1. INTRODUCTION

A spring can be considered a universal symbol for oscillatory motion and vibration. Its simplicity and powerfulness stems from being a tangible object whose shape, length, motion and especially vibrating kinetic energy, can be easily *felt* and modified through simple hand manipulation. This is clearly understood when one thinks about toy-like devices based on a coil, such as the immensely popular SLINKY™.

Throughout time, philosophers and composers have been fascinated by the direct relationship between sound and vibration. K. Stockhausen whose musical works often include devices that link the boundaries of pitch, rhythm and vibration, took this discussion to a greater level, speaking eloquently about vibration as the common denominator of all things in the universe and relating sound to life itself [1].

Building a new instrument whose interface is simultaneously the symbol of vibration and the actual mechanism that triggers the production and modification of sound was thus very appealing.

The Sonik Spring uses primarily kinesthetic feedback as means of transmitting cognitive input to its user. Because it is handheld and controlled by spatial and gestural motions of the arms, wrists and fingers, the interface provides many degrees of complex muscular response and sensory stimulation.

One of the most common and pertinent criticisms about the performance capabilities and expressive potential of new electronic music instruments has been their lack of feedback response, frequently of kinesthetic nature. This insufficiency lessens the musical experience and hinders the new instrument from attaining the status of a "real," acoustic-like, performance savvy instrument [2] [3] [4].

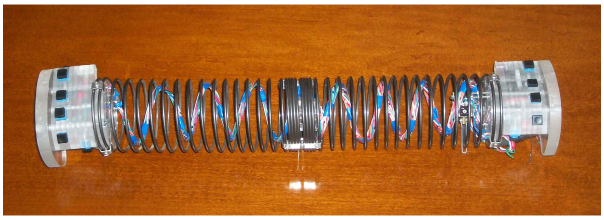

Figure 1. The Sonik Spring

The Sonik Spring was built from the ground up with the goal of creating an instrument that offers full immediate kinesthetic feedback. This is accomplished by virtue of the coil's resistance, which directly offers a strong sense of connectedness with the interface. Holding and manipulating the Sonik Spring is meant to feel like holding and shaping sound with one's own hands! Much in the way a sculptor works, the player of the Sonik Spring massages the sound, making it a clay-like material that is in constant metamorphosis. The Sonik Spring takes an approach to sound production, sound processing and music performance that empowers a musician to fully control sound in real time.

2. RELATED WORK

Research in kinesthetic based perception reveals force feedback as a stimulus deeply grounded into the human cognitive system [5] [6]. In the recent past, efforts have been made to introduce force feedback into the realm of digital controllers. One of the earliest experiments was done by Michel Waisvisz with the Belly-Web, a wire lattice similar to a spider's web [7]. In this interface the user's simple and intuitive finger movements pushing on the wires is made to alter their tension, which is detected by resistive sensors. The resulting changes are then translated into a set of control variables. Another such experiment was the Harmonic Driving, one of the controllers that was a part of the Brain Opera. It consisted of a large compression spring attached to a bike's steering gear, which was used to control/drive musical events [8]. The spring's bending angles are measured using capacitive sensors that detect the relative displacement between two adjacent coils while torsion is obtained with a potentiometer that rotates as a function of the relative angle between the top and bottom of the spring. More recently other controllers have been introduced that address the issue of force feedback, such as the Sonic Banana [9] and the G-Spring [10]. The Sonic Banana uses four bend sensors linearly attached to a 2-foot long flexible rubber tube. When bent it maps the data from the sensors to sound synthesis parameters. Due to the relative softness of the rubber tube this controller offers limited feedback when compared to the G-Spring, which measures bend as well. It features a heavy 25-inch close-coil expansion spring, and uses light-dependent resistors to measure the varying amount of light that slips through the coils as a function of the amount of bend. Variations in bend are then mapped to synthesis parameters.

Figure 2. Expanding the spring's length

Unlike the controllers above described, the Sonik Spring uses accelerometers and gyroscopes to measure complex spatial motion. As an interface, it physically offers greater flexibility since it can be compressed, expanded, twisted or bent, in any direction, allowing the user to combine different types of intricate manipulation. Also, because the Sonik Spring is portable, wireless and comfortably played/held using both hands, it allows a higher degree of control and it looks and feels like a performable, "human-scaled" instrument.

3. DESIGN

3.1 The Interface

Choosing a spring with the right force feedback resistance was paramount to this project. The goal was to get a spring that could be *both compressed and extended* and that could provide an ideal amount of force feedback pressure when changing its length. By ideal I mean a feedback force that was strong, enabling the user to feel and "fight" the resistance offered by the spring, while at the same time, allowing it to be fully compressed and freely extended to various lengths.

The Sonik Spring features a coil with a diameter of 3 inches and an unstrained length of 15 inches. The spring is attached at both ends to hand controller units made out of plexiglass. These consist of circular shaped plates designed to being comfortably grasped while allowing the user's fingers to move freely. The plates connect to a structure that houses and conceals most of the electronic components. Each hand controller contains sensors that detect spatial motion in three dimensions as well as five push buttons.

Figure 3. Left hand controller, 4 push buttons displayed

The spring can be extended to a maximum length of 30 inches and compressed down to 7 inches when fully collapsed. It therefore allows a length variation ranging from approximately half its size to exactly twice the length. These proportions, covering a 4:1 ratio, prove to be uniquely useful and intuitive when applying mappings of the spring's varying length to simple linear changes in musical parameters that are perceptually immediate.

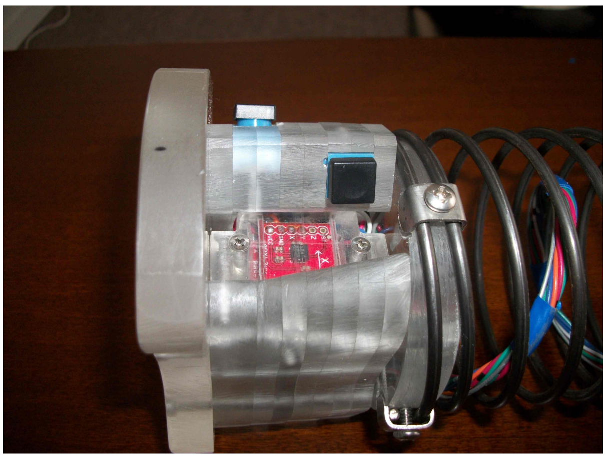

Fig. 4. LH unit: accelerometer, thumb and index switches

The relevance of a string with the characteristics described above, becomes apparent when one considers the possibility to not only compress and extend its length, but to be able to bend and twist it as well, and doing so simultaneously. This remarkable flexibility allows the user to perform many different types of shape and length manipulations that can be mapped to sound and music parameters.

Working in tandem with the primary kinesthetic feedback of the spring is the important visual feedback component [11] [12], directly linking the amount of force exerted on the coil with a gestural/spatial representation of that effort. This dual quality emphasizes the uniqueness of the interface.

3.2 Sensing complex motion

The Sonik Spring senses variations in spatial motion and orientation using a combination of accelerometers and gyroscopes. Three groups of 2-axis accelerometers coupled with 1-axis gyroscopes were devised and placed in three strategic locations within the interface: one group at each end of the spring and one group at its exact middle. This is so to fully capture the very many possibilities of spatial motion, especially those related to various types of torsion and bending. Variations of motion in the lateral, longitudinal and vertical angles of rotation will be described in this paper using the terms pitch, roll and yaw, borrowed from flight dynamics.

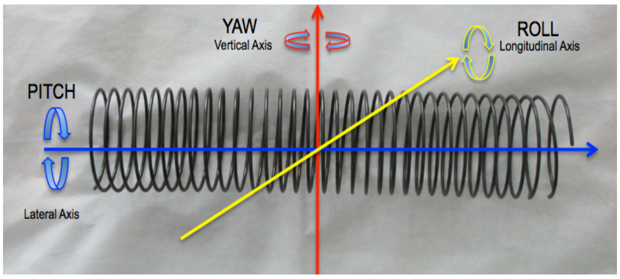

Figure 5. Spring's three axes of rotation

The simplest way to explore changes in the spring's orientation is accomplished by using *both hands* synchronously to perform the *very same* type of *wrist driven* rotating actions, doing so for each one of the 3-spatial dimensions. In this scenario the sensors at both ends and middle of the spring would have similar readings since they would be moving in exact parallel motion. If on the contrary, a performer bends and twists each hand independently, using different force amounts, such as shown in figure 6, complex shapes in the spring are created requiring all sensing elements to be separately analyzed. In this case, the fluidity of the spring's shape makes the acquisition of sensor data to have to rely on the combined result of their readings.

Changes in the spring's length are measured using the data from one axis of a small joystick. The joystick is built into the right hand controller and its shaft is connected to a long necked hook, attached to a nearby and carefully chosen ring of the spring. When the spring changes its length, that ring along with all others gets displaced, and the distance it covers drags the shaft with it giving an accurate measurement of the spring's overall change in length. This simple solution has proven to be very reliable for the purpose it serves unlike previous experiments done with different sensors. Those included an hall-effect sensor placed at one end of the spring and actuated by a small magnet attached to a nearby ring, and a 10-turn potentiometer attached to the right hand controller, driven by a retractable wire attached to the opposite end of the spring on the left hand unit.

Figure 6. Bending the interface in a complex way

The results of these experiments revealed to be impractical. The hall-effect sensor provided inconsistent readings and the retractable wire would occasionally get entangled in the rings of the spring.

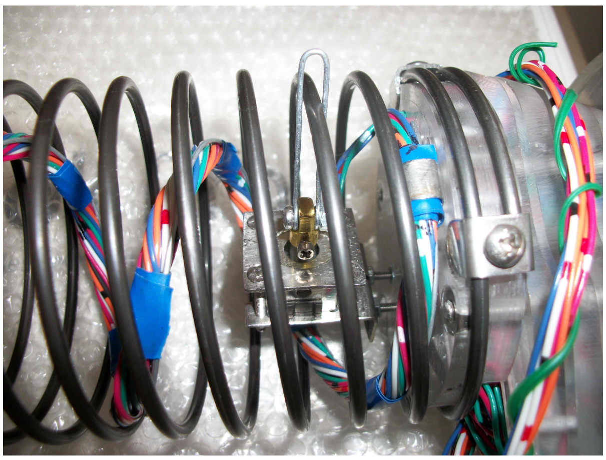

Figure 7. Measuring length variation with a joystick

The hand controller units contain five push buttons each. They are strategically placed for the fingers to rest comfortably on them. Each button is meant to he triggered by a single specific finger. One of the major roles of the buttons consists in enabling or muting the readings of the spatial sensors allowing the data to be properly routed and processed.

3.3 Sonik-Spring: A Two-Spring Mass System

The Sonik Spring is most often used pushing or pulling both ends in opposite directions, continuously varying the distance between them. Conversely, the user can manipulate the spring by keeping both arms at the very same distance while rotating the interface within the three spatial axes. But there is yet another way to explore the unique physics of this interface, given the particularities of its construction.

Since a group of sensors were placed in the center of the spring they make up for a small weigh behaving as a mass in a classic spring-mass system. This arrangement offers the possibility to generate oscillatory motion of this center mass by shaking the spring either longitudinally or transversely, with different force amounts, and whilst keeping both arms/hand units at the same distance.

In the Sonik Spring the center weight acts upon both halves of the spring, turning the interface into a two-spring mass system, with both halves having similar spring constants. Figure 9 shows the housing of those sensors and also depicts a group of 10 rings that were compressed and linked together so as to mechanically facilitate to secure the sensors in place, thus further contributing to the definition of a center mass.

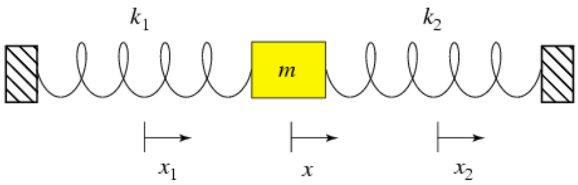

Figure 8. Two-spring mass system

When the mass *m* is displaced by a distance *x,* it makes the "first" spring to lengthen by a distance x1 (pulling with a force in the –x direction) while the "second" spring is compressed by a distance x2 (pushing with the same force in the –x direction too). Knowing that both halves of the Sonik Spring share the same spring constant, that is, k1=k2 with the amount of extension x1 equaling the compression x2, the equation of motion and the frequency of the mass oscillation can be calculated as follows:

$$ma = F \qquad ma = -kx$$

$$ma = -k1x - k2x = -(k1 + k2)x$$

$$k1 = k2$$

$$ma = -2kx$$

$$a = -(2kx)/m$$

$$\omega = \sqrt{2k/m}$$

$$T = 2\pi\sqrt{m/2k} \Rightarrow f = 1/2\pi\sqrt{m/2k}$$

The accelerometer and gyroscope placed in the center of the spring are used to measure the rate of oscillation of the mass of the system. The displacement of this mass and the cyclic way the rings compress and extend is visually very apparent. This quality suits the interface to being used rhythmically, in a very tangible way, to generate events such as short percussive sounds, etc, whose nature can be made to evolve as a function of the oscillatory energy of the interface. The rate of oscillation can also been mapped to more subtle parameters such as the frequency of an oscillator driving an amplitude modulation algorithm, etc.

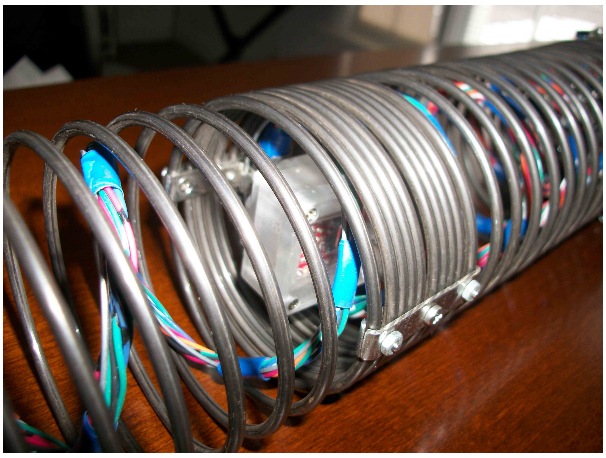

Figure 9. Accelerometer and gyro at coil's middle point

3.4 Channeling the sensor data

The Sonik Spring uses a MIDItron wireless sensor interface to collect the information acquired by the ten analog sensors and ten digital switches [13]. The analog sensor data is formatted as MIDI continuous controller messages and the on off states of the switches as MIDI note on and note off messages. This information is sent to a computer running the MaxMSP software which does all the data processing. Working with a wireless sensor interface has proven to be invaluable since it allows the spring to be completely and freely manipulated.

4. PLAYING THE SONIK SPRING

The Sonik Spring can be used in different ways. Three relevant 'performance modes' have been identified. These are: Instrument mode, Sound Processing Mode and Cognitive Mode.

4.1 Instrument Mode

In *"Instrument mode"* the Sonik-Spring is played as a virtual concertina, using the gestural motions commonly associated with playing this instrument while adding new performance nuances unique to the physical characteristics of the spring. In its current implementation the instrument can either use a MaxMSP patch that controls the generation of sounds based on a physical model of an air-driven vibrating reed [14] [15] [16], or it can process the sensor data sending it via MIDI to commercial hardware and software synthesizers.

To play the Sonik Spring the performer holds it horizontally, with both hands, comfortably grabbing the instrument. The sensors of the left hand unit trigger the generation of chords while those of the right hand generate melodic material.

The motion of pulling and pushing the spring emulates the presses and draws of virtual bellows using the tone generation technique of an English concertina. The amplitude of those gestures is mapped to the loudness of the sound.

The accelerometer and the five push buttons of the right hand unit are combined to generate the melodic material. This is accomplished using fingers index through pinky, to access 4 buttons that borrow the pitch generating method of a 4-valve brass instrument, allowing the production of the 12 chromatic tones within an octave. Changing the springs' "pitch" by rotating it in the lateral plane maps the accelerometer data to select the desired pitch-octave, triggered by pushing the button assigned to the right hand thumb. A total of 6 octaves can be comfortably selected. Melodically, the Sonik Spring can thus simulate an instrument with 72 air-blown free reeds.

The loudness of the tones produced by the instrument is a function of both the absolute length of the spring as well as the amount of acceleration force exerted to make that length change from its previous position. The rate (speed and acceleration) at which the length changes is given by the joystick's displacement and by the combined data from the three accelerometers, being assigned to changes in loudness using different mapping strategies [17]. A crescendo is achieved by continuously pulling the spring outward. A diminuendo is done with the opposite action. A sudden and strong pull or push on the spring translates into a loud sound, etc. Furthermore, notes played in staccato are triggered by pairs of short bursts of pushes/pulls of the spring while legato notes are obtained by keeping the spring still lengthwise, and changing notes with the buttons of the right hand.

Pitch bend and glissandi effects are also possible by mapping changes in "roll" and "yaw" using the right hand's accelerometer and gyroscope, respectively.

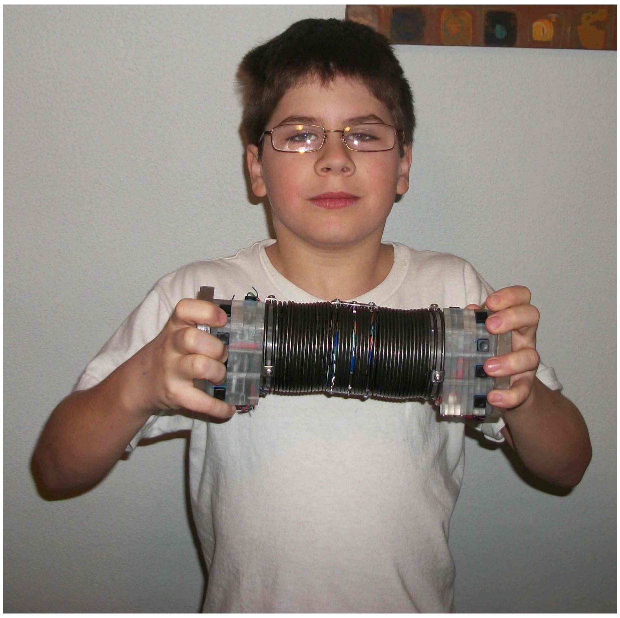

Figure 10. Spring fully collapsed

Pitch bend and glissandi effects are also possible by mapping changes in "roll" and "yaw" using the right hand's accelerometer and gyroscope, respectively.

Chords are generated using the five push buttons, the accelerometer and the gyroscope of the left hand controller. The software that generates the chords is largely based on the author's previous work implemented in the wind controller META-EVI [18]. Chords can have anywhere from 0 to 4 notes. This allows the muting of the harmonic functions or use the left hand controller as a simple drone or counterpoint line if the number of chord voices is just one.

The type of harmonies that can be played depends upon the choice of a target 'home-key' gotten from a combination of four push buttons (using again the 4-valve brass technique) to select one of twelve different pitches and the button for the thumb to select minor or major mode. Once these choices are made, the very same four buttons select the 'scale degrees', which provide different chord types. Since chord types are software dependent it is possible to chose 'non-tonal' chords from a large array of options if desired. Chord inversion is implemented by mapping variations in the amount of "roll" of the left hand controller. Changes in chord voicing varying the register of the chord's notes, is implemented by mapping changes in the "yaw" position. The overall loudness of the chords is mapped to the "pitch" position of the left hand controller.

As far as changes in the timbre of the sound produced by the physical model, they are obtained by mapping a series of gestural motions into synthesis and control parameters. A vocabulary of a small group of such gestures has been implemented and it has proven to be a simple and effective way to correlate visual to auditory information [19] [20].

a) Twisting the hand units symmetrically in opposite directions and with the same force to map changes to Filter Cutoff frequency
b) Twisting the hand units symmetrically in opposite directions while bending the spring down to map both filter cutoff *and* resonance
c) Bending the spring so that it defines a "U" shape mapping that shape to LFO rate, acting on the pitch being played
d) Bending the spring so that it defines an inverted "U" shape, mapping it to LFO amplitude
e) Shaking the interface along its lateral axis to map oscillation of the center mass to the frequency of an oscillator doing amplitude modulation

4.2 Sample Processing Mode

The Sonik-Spring can be used as a controller for real-time sound processing. In its current implementation the software uses a granular synthesis engine to playback and process sounds stored in memory [21].
The many degrees of gestural motion that the interface offers, allows the performer to convey a strong connection between the actions taken on the spring and the auditory outcome on the sound being processed in real time.

Mapping the variation of the length of the spring to different parameters, switchable using push button presses on the right hand controller, achieve the best results as far as the correspondence between the auditory and visual domains. The most striking use of the length variation is to map it to classic pitch transposition where both pitch and tempo are simultaneously altered. Holding the sound playback and performing scrubbing effects, forward or backwards, on a short section of a sound, by extending and compressing the spring, is also perceptually rewarding.
Mappings of the left hand accelerometer include the independent control of a sound's pitch and playback speed by respectively varying the spring's lateral and longitudinal axial rotations, that is, its 'pitch' and its roll. The gyroscope of the left hand controller, detecting the spring's yaw, is used to perform panning changes on the sound being processed.

The switches of the right hand are use to perform tape-like "transport functions". Therefore sounds can be triggered forward or backwards, stopped, paused, muted and can be looped. It is also possible to choose variable loop points and isolate a chunk of an audio file anywhere within its length, with the capability to trigger the loop start point at will thus creating rhythmic effects.

The sensors of the right hand are used to perform additional functions such as control grain duration and randomize playback position. They are also used to control parameters that perform amplitude modulation and filtering on the samples.

Figure 11. Spring bent downwards – Inverted U shape

4.3 Cognitive Mode

An interesting use of the Sonik Spring is as a tool to test different sensorial stimuli. At an immediate and simple level, it can be used to gauge an individual's upper limbs muscle and force responsiveness by directly linking variations in a sound's parameter such as pitch or loudness, to variations of the spring's length. A more complex approach to study an individual's level of cognitive perception can be done by simultaneously linking auditory, visual, spatial and force feedback. This last scenario is especially promising to medically assess people with neurological challenges [22].

5. CONCLUSIONS AND FUTURE WORK

The Sonik Spring has proved to be a very versatile instrument and an interface that it is a lot of *fun* to play with. People of different ages and with different musical backgrounds have tried it and the results show that the *Sample Processing Mode* is by far the most popular performance mode.

Using the instrument as a virtual concertina is also musically rewarding. The interface is agile, responsive and highly expressive allowing the user to develop performance skills that could reach virtuosity.

A growing interest in the use of the interface in Cognitive Mode is also evident. Collaborations with researchers in the medical field are planned.

Future work will focus on taking advantage of combining and networking the data from all sensors so as to apply "many-to-one" mapping strategies. This will reveal new meaningful information, useful for the control of synthesis parameters when the instrument is being played with a physical model, increasing the high level of feedback that it already conveys. More research is also planned to continue exploring the two-spring mass system. Of relevant interest is the inclusion of user generated oscillatory motion to affect synthesis parameters of the physical model being used to generate sound.

6. ACKNOWLEDGMENTS

This research is made possible through the support of the Portuguese Foundation for Science and Technology (grant UTAustin/0052/2008) and the UT Austin | Portugal Program in Digital Media. I also would like to thank my father, Vitorino Henriques, for his craftsmanship and dedicated help building the hardware.

7. REFERENCES

[1] J. Harvey. *The music of Stockhausen: An introduction.* University of California Press, 1975.

[2] P. Cook. *Principles for designing computer music controllers*. In Proceedings of the New Interfaces for Musical Expression Workshop, 2001.

[3] Marcelo M. Wanderley and Nicola Orio. 2002. *Evaluation of Input Devices for Musical Expression: Borrowing Tools from HCI*. Computer Music Journal, vol. 26, number 3, pp. 62-76.

[4] S. O'Modhrain. *Playing By Feel: Incorporating Haptic Feedback into Computer-Based Musical Instruments*. Ph.D. diss., Stanford University, 2000.

[5] FJ Clark and K W Horch. *Kinesthesia*. In Handbook of Perception and Human Performance. Vol. 1, Sensory Processes and Perception. ed: KR Boff, L Kaufman, JP Thomas. 1986: Wiley & Sons, NY.

[6] LA Jones, *Perception of Force and Weight: Theory and Research*. Psychological Bulletin 1986, Vol. 100, No. 1, pp. 29-42.

[7] http://www.crackle.org/Waisvisz%27%20Small%20Web%20%28Belly%20Web%29.htm

[8] J. Paradiso. *The brain opera technology: New instruments and gestural sensors for musical interaction and performance*. Journal of New Music Research, 28(2): 130–149, 1999.

[9] E. Singer. Sonic banana: *A novel bend-sensor-based MIDI controller*. In Proceedings of the International Conference on New Interfaces for Musical Expression pages 85-88, 2006.

[10] D. Lebel and J. Malloch: *The G-Spring Controller.* In Proceedings of the International Conference on New Interfaces for Musical Expression, pp. 220-221, 2003.

[11] J. Davidson. *Visual perception of performance manner in the movements of solo musicians*. Psychology of Music, 21:103–113, 1993.

[12] Cadoz and M. Wanderley. Gesture-music. In M. Wanderley and M. Battier, editors, *Trends in Gestural Control of Music*, pages 71–93. IRCAM – Centre Pompidou, Paris, 2000.

[13] http://www.eroktronix.com/

[14] J. Cottingham. *The Motion of Air-Driven Free Reeds*. In Collected Papers of the 137th Meeting of the Acoustical Society of America, 1999.

[15] L Millot, V. Debut. *Time Domain Simulation of the Diatonic Harmonica.* In Mosart Workshop on Current Research Directions in Computer Music, Barcelona Spain, 2001.

[16] D. Howard, S. Rimell, A. Hunt. *Force Feedback Gesture Controlled Physical Modeling Synthesis*. In Proceedings of NIME, NIME-03, McGill University - Montreal, Canada, May 22-24, 2003.

[17] A. Hunt, M. Wanderley, M. Paradis. *The importance of parameter mapping in electronic instrument design*. In Proceedings of NIME, NIME-02, Dublin, Ireland, May 24- 26, 2002.

[18] T. Henriques. *Meta-EVI: Innovative Performance Paths with a Wind Controller*. In Proceedings of NIME, NIME-08, Genoa, Italy, June 2008.

[19] C. Cadoz. *Instrumental gesture and musical composition.* In Proceedings of ICMC 1988, pp.1-12.

[20] A. Mulder. *Toward a choice of gestural constraints for instrumental performers*. In M. Wanderley and M. Battier, editors, Trends in Gestural Control of Music, pp. 315–335. IRCAM – Centre Pompidou, Paris, 2000.

[21] A. Gadd and S. Fels. MetaMuse: *A Novel Control Metaphor for Granular Synthesis.* In Proceedings ACM Conference on Computer Human Interaction. SigCHI, ACM, 2002.

[22] B. Wen. *Multisensory integration of visual and auditory motion*. In Neuroscience. Issue: May, pp. 1-6, 2005.