The G-Spring Controller

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ABSTRACT

This paper presents a novel digital musical instrument using an interface constructed from a large spring that offers natural kinesthetic feedback through its inherent stiffness. The design of the first prototype is described and discussed in relation to the notion of effort in musical performance. Audio feedback and distortion are introduced as a possible way to extend the musical limits of the simple interface.

Keywords

Digital musical instrument, kinesthetic feedback

1. INTRODUCTION

The concept of effort in musical performance is often referred to in the context of digital musical instrument (DMI) design. Tanaka, for example, observes that sensor-based instruments often lack the sophisticated inherent feedback feature that demands physical effort in manipulation [14], and asserts that this difference holds back the enjoyment and acceptance of DMIs. Furthermore, although the design of these allows for a reduction in required performer effort, many consider that without this effort an instrument cannot be performed expressively [12, 10].

The G-Spring design is inspired by this notion of effort. Using a physical interface with inherent kinesthetic feedback, it may be possible to create a DMI that feels more like a traditional acoustic instrument, which may in return open doors to higher expressivity for the performer [2]. The instrument – despite its digital nature – will hopefully appeal more to the performer and audience as a response to the feedback manifested through the performer effort [14].

In [16], Wessel and Wright discuss the "low entry fee with no ceiling on virtuosity" design approach. They mention that traditional acoustic instruments are typically not easy to learn, but provide for a high degree of musicality. When talking about the simplicity of some DMI interfaces, they point out that one quickly surpass the interface by discovering its limits, which highly contrasts with traditional instruments.

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Along the same lines, a way to reach a balance between an easy-to-use interface and continuous musical evolution is explored with the G-Spring. It is an attempt to design an instrument with a simple interface that produces sound easily, but afford musical complexity through additional and more refined controls. Through practice, these qualities can be used by a performer to create unique sounds and push the musical limits of the basic instrument.

The remainder of this paper describes the design of the G-Spring, shown in Figure 1, and explains how effort is introduced by the choice of material as well as how possibilities for continuous musical evolution are investigated through the use of performer-controlled audio feedback and built-in distortion. The controller design is briefly evaluated and discussed in regards to the notion of effort. Finally, some directions for future work are outlined.

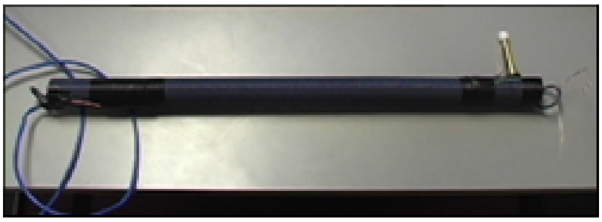

Figure 1: The G-Spring controller.

2. RELATED WORK

The G-Spring is superficially similar to the Sonic Banana [13]. Both controllers measure bending and map it to numerous sound synthesis parameters. In the Sonic Banana, four bend sensors are fixed linearly inside a flexible rubber tube to measure its bending. The interface differs in that little physical force is required by the performer to bend the Sonic Banana due to its high flexibility, whereas the G-Spring was designed with effort and kinesthetic feedback in mind.

Harmonic Driving, a controller part of the Brain Opera, is an interface that does provide kinesthetic feedback to the user. It uses a large open-coil spring as an interface for musical steering tasks, using capacitive sensing to determine the relative displacement between two adjacent coils [11].

Past DMI designs that use light-sensing include the Photosonic Disk [1], the Circular Optical Object Locator [7], and the Light Pipes [17].

3. DESIGN

3.1 Physical Interface

The G-Spring interface is meant to be bent and thus, in order to provide decent kinesthetic feedback, the material used for its construction needed to be fairly deformable while requiring a reasonable force to be bent. Furthermore, it had to return automatically to its equilibrium position when pressure is released from it. Although some rubber substances might have been suitable, it was judged that the simplest solution was to use a bendable spring.

The spring used, which is shown in Figure 1, is a large and heavy close-coil extension spring commonly found in garage door mechanisms. It measures 63.5 cm unstrained, has a diameter of 3.5 cm, and weighs 1.85kg, which makes it particularly comfortable when held in average-sized hands. Its stiffness and flexibility are moderate in that it can be bent such that both extremities touch each other without demanding excessive force.

A spring door stop was fixed at one of the extremities of the spring, but perpendicular to it (Figure 1, bottom). The door stop is meant to bend towards the center of the large spring.

3.2 Sensing Methods

Although bend sensors might initially seem like a more logical choice to measure the bending of the large spring, this approach is more problematic than useful. The spring coils are very compact and will quickly crush anything inserted in between them, which makes it particularly hard to fix sensors on the spring without destroying them. The radius of curvature of the spring (when bent) is quite large due to its dimensions and close-coil characteristic. A last observation to be made is that in order to allow free bending of the spring, attached sensors must be flexible in all directions. These requirements make standard bend sensors less than ideal. The density of the coils also prevents the use of capacitive sensing as in the Harmonic Driving controller[1].

In practice, bending the spring causes slight gaps to form between adjacent coils, allowing ambient light to enter the interior of the spring. Thus, a light-dependent resistor (LDR) was found more suitable and durable to measure the bending of the large spring, since the sensor and wiring do not actually need to be in contact with it. Fixed inside the spring (Figure 2, top), and positioned a little off-center to align with its most comfortable flexion point, the LDR provides an inexpensive way to determine the bending without restraining it.

In order to provide additional control on the sound synthesis, a force-sensitive resistor (FSR) was placed near one end of the spring. Electrical tape was used as an insulating layer to protect the external sensor from being damaged by the spring coils when it bends (Figure 2, middle).

A bend sensor was fixed against the spring door stop at the opposite end of the spring. It was fixed this way (Figure 2, bottom) to get a more accurate measurement of its bending by reducing the radius of curvature. Introducing this angle in the bend sensor causes a wider range of resistances from the sensor, thus differentiating small variations in the bending more easily [6].

[1]In the Harmonic Driving, the spring coils were distant from each other.

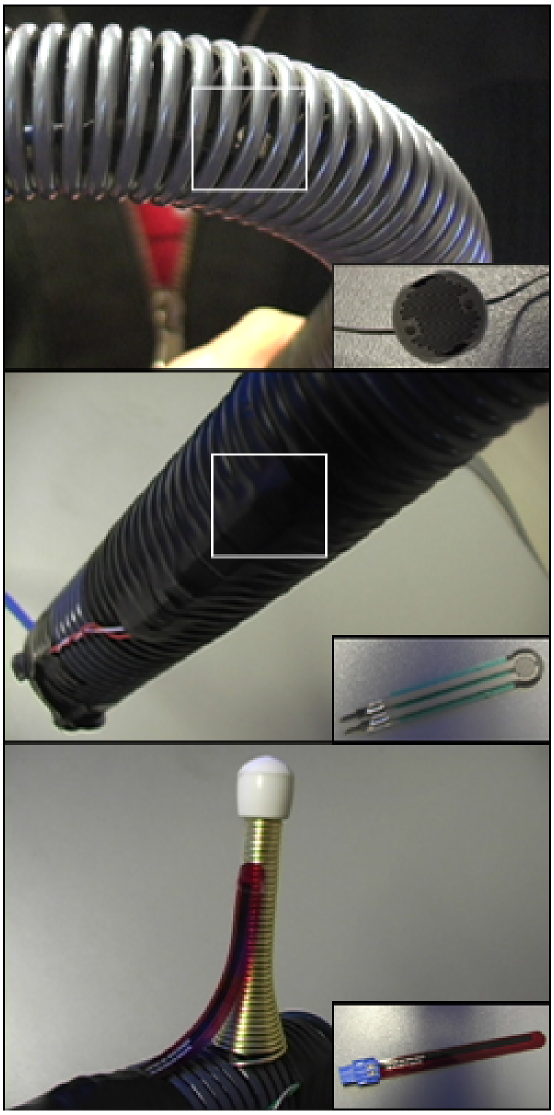

Figure 2: Sensors used in the G-Spring controller. Top: LDR inside the spring. Middle: FSR taped near one end of the spring. Bottom: Bend sensor fixed against a door stop at the other end of the spring.

3.3 Interface-Computer Communication

The communication with the computer is performed through USB, using a homemade AVR-HID device offering six analog input channels [9]. The AVR-HID is inexpensive and transforms the controller into a plug-and-play system that works on several systems including Windows, Mac OS X, and Linux.

3.4 Synthesis

The sound synthesis was implemented in Max/MSP and uses a source-filter model. The source is a bandlimited pulse wave rendered at low frequency (60Hz), which is fed into a bandpass filter with controllable center frequency, input amplitude and quality factor[2]. The resulting signal is processed by a comb filter, whose delay length, feedback coefficients, and feedforward coefficients are modulated.

[2]Quality factor is defined as the center frequency of the filter divided by its bandwidth.

3.5 Mapping

The output of the LDR is mapped to the center frequency of the filter. The center frequency is increased as more light hits the resistor. The control signal is mapped exponentially, which allows for a finer control over the lower frequencies and a coarser control of the higher frequencies[3]. The LDR signal is also mapped linearly to the quality factor of the filter.

A one-to-many mapping is used for the FSR [8]. The sensor output is mapped exponentially to the bandpass filter input gain and fed into a 2-second ramp, which allows for very smooth and continuous control of the sound. The global output gain of the synthesizer is also controlled by comparing the FSR value against a threshold level to cut off the sound as soon as the pressure is released.

The bend sensor is used to control the parameters of the comb filter. First, it controls the modulation frequency of the varying delay line length. It also controls the feedback and feedforward coefficients, which are modulated as well. In addition, a cutoff value is used to determine whether or not the door stop is being bent.

4. MANIPULATION

With the sensors in their current positions, the instrument can be manipulated with each hand holding one extremity of the spring. Bending the spring changes the range of frequencies that are let through by the bandpass filter. In general, the more the spring is bent, the higher the frequency range becomes, since more light reaches the LDR. The sound level is controlled by applying pressure on the FSR with the thumb of one hand. The higher the pressure is, the louder it is. The comb filter parameters are modified with the index of the other hand by bending the door stop towards the center of the spring.

It is perhaps more comfortable to stabilize one end on a stationary surface, since it makes it easier to smoothly bend the spring and helps counter its stiffness. Also, by fixing one end of the spring to a solid, stationary surface or stand, it could be bent more easily in any direction using both hands. This would also free the hands to directly modulate the amount of light detected by the LDR, by waving or placing them over the flexion point.

5. RESULTS AND DISCUSSION

5.1 Design Evaluation

The substantial weight of the spring enhances the overall feel of the controller: the performer has the impression of holding a tangible and robust instrument. The spring stiffness, however, makes it uncomfortable when manipulated over an extended period of time, since it requires that force be constantly applied on it in order to maintain a bent position. This also prevents any further addition of finger controls due to human biomechanics limitations. Thus, an instrument requiring a constant physical effort by the performer may not necessarily be desirable. In the G-Spring's case, a different mapping strategy, in which the bending of the spring controls some modulation, could be potentially more suitable.

The LDR works well at measuring the spring bending, although using only one LDR does not provide accurate measurements since the amount of light that reaches the sensor is not necessarily proportional to the bending. For example, if a part of the spring distant from the sensor is bent, or if the sensor is pointed away from the coil gaps, less light will illuminate the sensor.

The bend sensor provides a very fine control that is ideal for feedback parameters. The use of a cutoff value greatly enhances the capabilities of the instrument, allowing the performer to keep a certain set of feedback parameters during a performance by simply releasing the pressure on the door stop, which effectively stops modulation.

The ramp applied to the FSR control signal was judged to be the most successful mapping strategy of the instrument as it provides a very smooth and continuous control over the sound level and makes the instrument easier to play. Moreover, the cutoff applied to the output signal allows for the sound to shut off as soon as the pressure is completely released from the FSR, which is a very important feature to have in a musical system [16].

5.2 Continuous Musical Evolution

Even though the G-Spring interface is simple and offers few degrees of freedom, this does not necessarily mean the instrument can be mastered in a few minutes, or that it is sonically limited. The performer-controlled audio feedback allows the creation of a fairly wide spectrum of sounds, generated through precise manipulations of the instrument. By simultaneously modifying the center frequency of the bandpass filter (spring bending) and the feedback parameters (door stop bending), numerous sounds are possible. Furthermore, while applying a constant force on the spring, adequate control of the feedback parameters is challenging and requires practice before expert results can be created.

The calculation of the quality factor of the filter introduces distortion at certain frequencies. When sweeping the frequency range of the filter, the sound level varies from a moderate level at low frequencies, to a high level near 500Hz and then decreases to a very low level at high frequencies. This occurs due to the varying bandwidth of the filter. The distortion created in the mid-range frequencies acts as an additional parameter that can be used by the performer through control of the center frequency and amplitude of the bandpass filter. This can be further refined by simultaneously playing with the feedback parameters.

This suggests that the sonic possibilities of DMIs can be extended through clever synthesis and mapping strategies even though the controller interface is rather simple. In the G-Spring, the feedback and distortion definitely provide some complexity to the sound output. Unfortunately, not enough time was spent experimenting with these two parameters to clearly determine whether they really provide a way for continuous musical evolution, but it remains nonetheless an idea worth investigating.

5.3 Performance

Some subjects, mostly non-musicians, were asked to watch a short video[4] of a performance involving the G-Spring controller, without having encountered the instrument before. An interesting comment was made by the subjects regarding the lack of movement during the performance, saying that they felt less engaged by it. Consequently, what these subjects expressed was that the amplitude of the motion induced by the instrumental gestures, as defined in [3], was minimal and sometimes left the lis-

[3]Note that the instrument was originally intended to focus on low frequencies.

[4]Available on the project website:
http://www.music.mcgill.ca/~lebel/gspring/

tener/viewer without clear visual cues as to whether or not the performer was really involved in the sound modification process. Due to the inherent kinesthetic feedback of the spring and the mapping strategies implemented, mostly continuous, very precise and low-amplitude movements are used to modify the sound parameters. In other words, when bending the spring, a force needs to be constantly maintained, which limits the apparent motion of the performer. This suggests that although effort may help convey visual cues, the apparent motion of the performer's instrumental gestures also plays an important role in the understanding and appreciation of the instrument and the performance by the audience [5].

People who tried the instrument enjoyed the fact that it produces sound instantly, which supports the "Instant music, subtlety later" principle stated by Cook in [4]. The sound modification controls are also easily grasped due to the visualization of the filter parameters through a graphical filter object in Max/MSP. This suggests that the design of DMI interfaces do not necessarily need to be extremely simple, but rather can be used with visualization to ease the learning curve of the performer. Once a good intuition of the controller is gained, the instrument could then be used without visualization.

6. FUTURE WORK

Since increasing the ease-of-use of DMI interfaces is not necessarily desired by performers [10], and visual feedback seems to make the instrument control more intuitive, it would be interesting to investigate the use of control parameter visualization with complex interfaces. Also, a more in-depth and quantified study of kinesthetic feedback in regards to the ergonomics of interfaces would be useful to better integrate the notion of effort in the design stage of DMIs.

7. CONCLUSION

A new digital musical instrument was presented featuring inherent kinesthetic feedback, which requires physical effort by the performer to be played. The interface is intuitive, thanks to the visualization of the control parameters, while allowing for more complex and subtle modifications of the sound through user-controlled audio feedback and built-in distortion. Observations were made in regards to the importance of visual feedback for both the audience and the performer.

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