# An Inertial, Pliable Interface

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## ABSTRACT

In this paper we present an interface whose design is based on four concepts: interface physicality, integrality of control, inertial sensing and performer energy measurement. An interface prototype is described which integrates these concepts in its design and its implementation details are presented. Findings from the initial performance experiments are given which illustrate its the musical potential and limitiations.

## Keywords

Pliable interfaces, inertial sensing, integrality/seperability, performer energy.

## 1. INTRODUCTION

### 1.1 Physical Interfaces

As computer music interfaces allow increasingly virtual instruments, it is becoming clear that the visual, tactile and kinesthetic feedback they lack are essential for intimate instrumental control [13]. The obvious reaction is to create instruments that are physicalized as much as possible, allowing users to draw on their natural physical and spatial intuition in performance. Such an instrument could be played by direct physical manipulation, a very natural activity.

This reaction has already appeared in the field of Human-Computer Interaction (HCI). Work such as [3] and [7] shows how physical actualizations of virtual objects can leverage our natural human capabilities to produce much more compelling systems than standard computer interfaces provide. Balakrishnan et al. investigated the use of a bend-sensitive strip to control spline curves for computer graphics modeling applications [1]. They found that desired shapes could be created more quickly and naturally than with traditional mouse-based techniques. Direct interface manipulation is very effective in this context, and provides further motivation to explore this type of interface for music. In the musical domain, Eric Singer created a long, thin MIDI controller that used bend information at various points along its length to control musical processes [15]. The object is is played through bending and deformation. It "encourages experimentation to explore what sort of bending and twisting gestures produce interesting musical effects."

### 1.2 Integrality

Instrumental control can be seen as simultaneous, high dimensional multi-parametric input [18]. Traditional acoustic instruments require that a large number of physical parameters be controlled simultaneously by the performer. These cannot be isolated and manipulated individually. Jacob et al. show that it is important to match the interface to the perception of the task at hand, and that integral tasks require integral input devices [8]. Thus, a highly multi-parametric, integral input device would be appropriate in a musical context. Hunt and Kirk demonstrate this, and make a distinction between *analytical* and *holistic* modes of thought [5]. Highly integral interfaces need to be thought of holistically, and lend themselves to learning and exploration rather than analytical understanding of their workings. The same is true with traditional instruments: performers learn to play acoustic instruments, not control them.

An example of a highly integral controller of this type is the Web, created by Michel Waisvisz [9]. It consists of a number of wires strung across a frame, attached to tension sensors. The performer applies pressure to part of the web, mechanically distributing force to many sensors simultaneously. With one gesture, many parameters are influenced at once. The performer must learn how to control the instrument through experience and not a theoretical understanding of its workings.

### 1.3 Inertial Sensing

In many instruments, the way in which they are positioned can greatly influence the overall quality of the output sound [17]. Similarly, the way that an instrument is maneuvered through physical space can also affect the way the instrument produces sound [17]. Thus, it is desirable to have positional and movement data corresponding to the instrument. An affordable solution to this end is to use inertial sensors, i.e. gyroscopes and accelerometers.

Two orthogonal accelerometers may be used to determine the pitch and roll of an instrument. A third accelerometer may be added to determine its total attitude, referenced from gravity. If three orthogonal gyroscopes are added, it is possible to determine its orientation in six degrees of freedom.

Inertial sensors have been implemented in a variety of controllers. Accelerometers have been used to sense bodily movement in shoes [11], gloves [14], or gestures in batons [10]. Typically in electronic instruments, accelerometers have been implemented, yet there are many reasons to use both accelerometers and gyroscopes [16].

Society's desire to integrate inertial sensing with mechanical and electronic devices has given rise to modestly priced high resolution piezoelectric accelerometers and gyroscopes. Musician's desires to integrate these devices into electronic musical instruments is self-evident, and it is in this spirit that we have incorporated them into a new instrumental interface.

Given a three-dimensional position vector determined by the sensors, deviations in the positional orientation may be mapped to a modification in the sound. In this sense we take the movement of the performer to represent a modification gesture [2]. At the same time, from an inertial sensor we may determine the amount of energy expended by the performer in gesture. Drawing from the conventional model of an instrument, this value of energy [6] may be used as an amplitude envelope in which case we would find the same movement to be an excitation gesture. This duality in the gestures enhances the instrument as a focal point of the performer, and can make for a more engaging experience for both the performer and the audience.

## 1.4 Energy

In a mass-spring harmonic oscillator the kinetic energy associated with the mass is proportional to the squares of both the amplitude and frequency of oscillation. This paradigm shows that if the instrument is supplied with energy in an oscillatory fashion we can control the energy by varying the amplitude or varying the frequency of oscillations.

With a sinusoidal input we can elicit a gradual crescendo with a low frequency input that gradually increases in amplitude. A rapid change in instrument output amplitude is attained by a rapid change in activation frequency. The performer can educe tremolo by sustaining the energy of oscillation in the activation hand while alternately strengthening and loosening their grip in the supporting hand. Flowing gestures with the arms can produce predictable, desirable results. Alternatively, the instrument may be drummed or tickled to produce long sustained notes with interesting qualities.

In this paper, we present a prototype interface which integrates a deformable physical artifact with high dimensional integral control, inertial sensing capabilities, and a focus on performer energy.

## 2. IMPLEMENTATION

Our prototype interface integrates all of these design features. It consists of a pliable foam pad with embedded bend sensors to detect deformations. These sensors are concealed by another foam sheet and are not visible to the performer. Accelerometers are used to sense overall movement of the object. These are mounted in a rigid assembly that can be tapped or shaken by the performer. Sensor signals are digitized by an AtoMIC Pro [4] and are sent to the computer via MIDI. Signal processing, mapping and synthesis are performed using Pure Data [12]. The instrument energy is computed in software and used to drive sound synthesis appropriately. A photo of the prototype can be seen in figure 1.

**Figure 1: The interface prototype.**

## 2.1 Pliable Surface

A number of issues had to be addressed in order to get the bend sensor signals working reliably. The sensor rest values were not exactly zero as the mounting of the sensors caused some initial bend. A calibration procedure was developed that measured the MIDI value at maximum bend and at rest for each sensor. The bend sensor signals were bound to these intervals and normalized. The calibration procedure was as follows: reset and enable the calibration mechanism; bend all of the sensors to their most acutely bent positions; leave the pad at rest and capture the rest position; and finally disable the calibration mechanism.

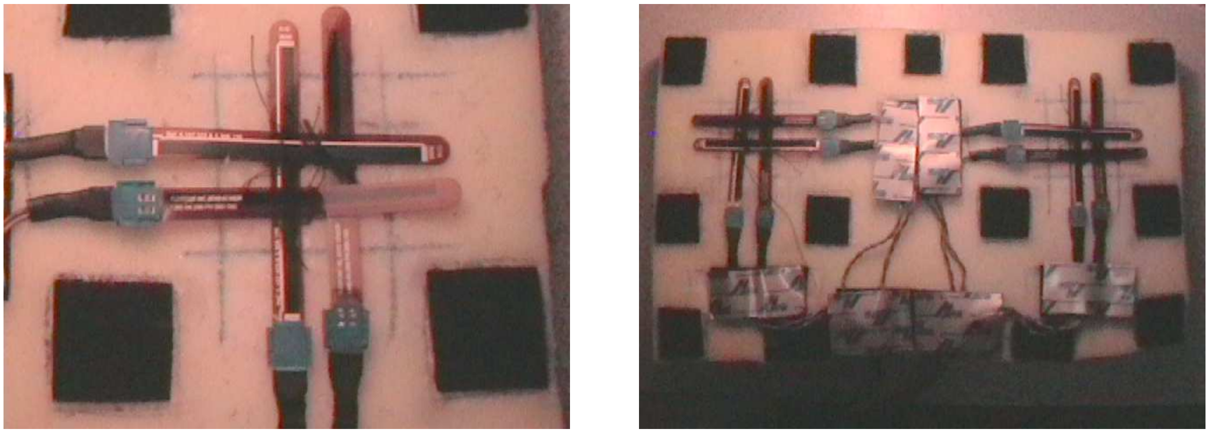
The bend sensors used could only measure bending in one direction, so in order to measure negative curvature the sensors had to be arranged in pairs with opposite orientations. One sensor measures positive curvature and the other measures negative curvature. For each pair, one sensor was mapped to a $(-1, 0)$ interval, and the other to $(0, 1)$. At most one sensor in each pair would be nonzero at any given time, so the actual curvature could be determined by adding the two values. Thus, the total curvature for a pair was expressed on a $(-1, 1)$ interval.

Two sensor pairs were arranged perpendicularly on the pad to obtain curvature along two axes for a given surface point. Figure 2 shows photos of the assembly illustrating this.

## 2.2 Accelerometers vs. Gyroscopes

The prototype interface implements the accelerometer circuit outlined in figure 3. This provides us with a sensor network capable of determining energy and position for our synthesis purposes.

The analogue output of a single axis acceleration sensor is a vector corresponding to the orientation of the reference face of the chip with respect to gravity. While the accelerometer is useful in detection of initial movement, it is difficult to use in determining velocity as integration is necessary. Furthermore, if the chip is not completely orthogonal to gravity, it becomes necessary to decompose three vectors to determine acceleration in a given direction. To determine a change in position, the derived velocity component must be integrated again, providing at best a rough estimate in six degrees of



(a)

(b)

**Figure 2: Photos of the prototype's bend sensor assembly: (a) bend sensor pairs which measure positive and negative curvature along two axes at a single point; (b) the entire pad assembly.**

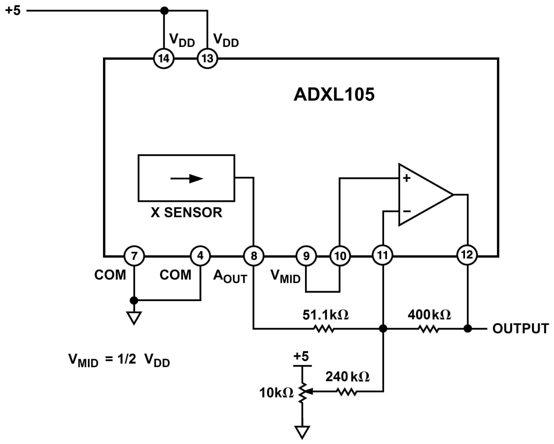


**Figure 3: Circuit diagram for one accelerometer.**

freedom. Quickly we can see that an accelerometer is not a desirable device in positional sensing, yet in a static environment can readily provide accurate information regarding the orientation in three degrees of freedom.

Gyroscopes, however, offer a simpler solution to the problem of finding dynamic characteristics of the instrument. The analogue output of the gyroscope is proportional to the angular velocity, eliminating the need for complex derivation and integration in the determination of energy.[1]

## 3. INSTRUMENT

The interface suggests a number of different uses as an instrument. It can be used to navigate through a timbre space, made to model and extend traditional instruments (e.g. a deformable tambourine), or made to work in some other way entirely.

Various mappings were explored over the course of prototyping the instrument. A map directly linking the bend sensor signals to synthesis parameters was created which proved interesting to learn and play. A simple synthesis model was used involving a square wave processed by a low pass filter, a flanger and a reverb. The sensor signals were scaled, fed into second-degree polynomials and summed to drive the frequency, pulse width, filter cutoff and volume of the synthesis process. Sixteen polynomials were used in total, linking each bend sensor pair with each synthesis parameter. The coefficients were adjusted manually, and included a large amount of feedback and crosstalk between the signals. Even for such a simple synthesis model, the instrument proved very expressive.

A second map was created in which pad deformation altered the trajectory of a point that moved through a timbre space according to an external process. This proved much less interesting as there was no longer a predictable relationship between the performer's gestures and the resultant sound.

We determine the energy of the signal by integrating the readings from the accelerometer and applying the equation of kinetic energy, $KE = \frac{1}{2}mv^2$. The sensors were found to be effective for this measurement, but noise and the required calculations complicated the process. This motivated the inclusion of gyroscopes, which will additionally allow for a more direct computation of relative angular position.

## 4. DISCUSSION

Because the performer is unaware of the distribution of the sensors and is unable to visualize them individually, he cannot approach the instrument from an analytical perspective. The performer must develop a mental model of the relationship between gestures and sound through exploration. This makes for an engaging instrument which encourages musical discovery, as evidenced by our experiences with new

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[1] Gyroscopes are currently being implemented and will be part of the impending version of the instrument.

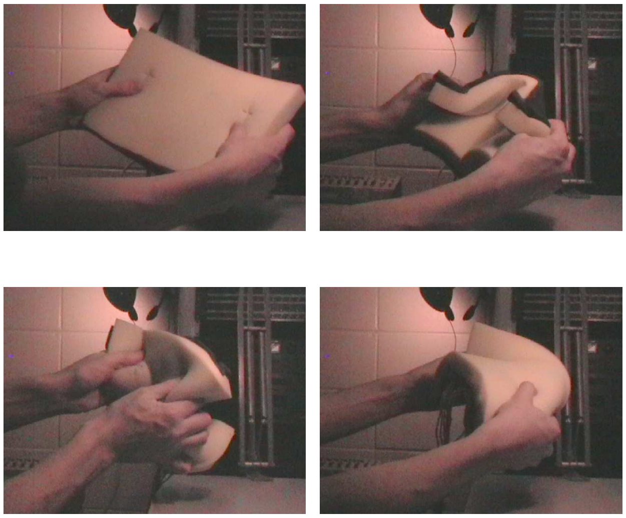

**Figure 4: A selection of deformation gestures.**

users; they enjoy learning which gestures produce interesting sounds and discovering the character of the instrument.

Similarly, exploration is also required for a sense of amplitude control. The instrument can take on qualities ranging from sharply percussive to subtle and sustained based on the performer's excitation gesture. The interrelationship between the inertial and bend sensors affords rich control possiblities.

## 5. CONCLUSION

Physically manipulable instrument interfaces provide tactile and visual feedback often lacking in computer music interfaces. Integrality of control allows for complex simultaneous manipulation of synthesis parameters, and promotes holistic thinking about the instrument. We have designed, prototyped and tested an interface which integrates these ideas with inertial sensors and a focus on performer energy. We believe that it has great musical potential when used in combination with appropriate mapping and synthesis algorithms.

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