The Kalichord: A Physically Modeled Electro-Acoustic Plucked String Instrument

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Abstract

We present the Kalichord: a small, handheld electro/acoustic instrument in which the player's right hand plucks virtual strings while his left hand uses buttons to play independent bass lines. The Kalichord uses the analog signal from plucked acoustic tines to excite a physical string model, allowing a nuanced and intuitive plucking experience. First, we catalog instruments related to the Kalichord. Then we examine the use of analog signals to excite a physical string model and discuss the expressiveness and form factors that this technique affords. We then describe the overall construction of the Kalichord and possible playing styles, and finally we consider ways we hope to improve upon the current prototype.

Keywords: Kalichord, physical model, tine, piezo, plucked string, electro-acoustic instruments, kalimba, accordion

1. Introduction

The Kalichord is a new plucked string instrument that combines acoustic and electric elements. At the heart of the Kalichord is a system in which the player plucks a few small tines that act as virtual strings. The tines each have embedded piezo elements which act as pickups, and the acoustic signal from these pickups becomes the excitation signal for a digital physical model of a string. This method of acoustically exciting a string model from a tine turns out to be surprisingly realistic and expressive as well as allowing for new form factors and performance styles previously unavailable to plucked string instruments. Using these new form factors, we sought to maximize the facility for simultaneously playing bass lines with one hand and arpeggios with the other. (This kind of two handed interplay is relatively easy on the piano or accordion, but is more difficult with most plucked string instruments.) In this way, we hoped to create an instrument that benefits solo musicians who want to play bass lines and chordal or melodic accompaniment simultaneously.

2. Related Instruments/Controllers

We used as inspiration a number of different existing instruments, including the acoustic guitar, the kora (West-African two-handed harp), the kalimba (African thumb piano), and the orchestral harp. However, our greatest influence was the button accordion. Like the accordion, the Kalichord has bass buttons under the left hand, melody notes under the right, and registers inter-hand motion in order to implement a similar "one-man-band" style of play.

The the use of tines for plucking was inspired in part by Adrian Freed's electric kalimba [1], which is itself a controller inspired by the african thumb piano. Freed uses control rate signals from wooden tines to measure the strength of the pluck and to capture aftertouch information.

The Thummer [2] controller has a similar form factor to the Kalichord, with a handheld model that features a matrix of buttons with expressive touch and some innovative new tunings.

There have been a number of guitar interfaces (such as the Ztar [3] and Yamaha EZ-GE [4]) that convert physically plucked signals into MIDI notes. There have

Figure 1: The Kalichord being played (left) close-up on tine-strings (right)

also been at least a few electronic instruments which use audio signals for excitation. The Korg Wavedrum, for example, used contact microphones underneath a drumhead to send excitation signals to a synthesis engine [5]. Edgar Berdahl & Julius Smith's tangible virtual vibrating string [6], discussed below, uses a heavily damped guitar string to excite a physical model.

3. Control of Physical String Models

3.1 Physical String Modeling

In physical modeling, the acoustics of the instruments themselves are often separated from the excitation stimulus (in this case, the plucking) and modeled independently [7]. For plucked string instruments, resonator and string acoustics have been studied extensively, but excitation signals have received less attention: they are generally either simulated using a filtered noise burst [7], or the pluck signal itself is extracted from a recording and stored as an excitation signal to be used later [8] (see figure 2).

There has been work done towards methodically modeling the finger-string interaction of an acoustic guitar, notably by Cuzzucoli/ Lombardo [9] and more recently by Eckerholm/ Evangelista [10]. However, we have not found controllers that can fully manifest the nuances of these models. Part of the problem is the sheer bandwidth of information that a guitarist is able to impart upon a string, from the exact angle of the plucking over time to the complicated flesh-fingernail-string interaction, to name a few.

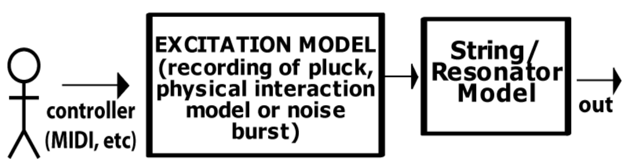

Figure 2:
Common Plucked String Physical Model Signal Flow

3.2 Tangible Virtual Strings

As an alternative, Berdahl & Smith demonstrated that a great deal of realism and expressiveness could be achieved by plucking a heavily damped string and using that signal at audio rates to excite a physical model [6]. In other words, the finger-string interaction is *measured* instead of *modeled*. There is an elegant simplicity to this approach, and we created the Kalichord as a way of further exploring it.

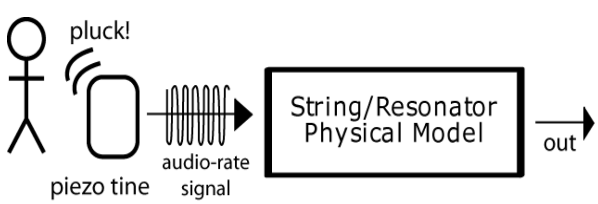

Figure 3:
Kalichord Tine Signal Flow

3.3 Use of Tines As Virtual Strings

The Kalichord further abstracts Berdahl/Smith's virtual guitar string by replacing the damped string with a tine pickup (figure 3). Like the damped guitar string, the analog signal from the piezo tine is digitized at audio rates and fed directly into a waveguide model of a string. We use the term 'audio rates' to mean typical CD or computer quality audio, at least 16-bit 44.1kHz (although 22kHz might be sufficient). This is in comparison to what can be called “control rate” signals often used for music controllers, which tend to be at a much lower sample rate (often 3kHz or lower). With the increase in power and lowered cost of today's audio interfaces, the use of audio rate controllers is now possible even for homemade instruments. (To determine minimum required sample rate, we lowpass filtered the signals prior to feeding them into the string model and informally determined that cutting frequencies lower than roughly 10 kHz really degraded the Kalichord's realism and playability. More rigorous testing in this area as well as opinions from various musicians is still necessary.)

3.4 New Form Factors

Because of their compact size, one can easily arrange tines in a much more condensed area than would be required for a full length of string. This opens up the arrangement of virtual strings into all sorts of configurations that are difficult (or impossible) with acoustic instruments: one could design for ergonomics, for the imitation of an already-existing instrument (such as a piano keyboard), or for visual aesthetics, among other possibilities. In the case of the Kalichord, the arrangement is primarily ergonomic, with the tines positioned just below the fingertips.

4. Construction / Play

The design of the Kalichord is similar to that of an accordion, with bass buttons on the left side and piezo tines on the right side (see figure 4). The current prototype

Figure 4:
Bass side (left) and tine-string side (right)

is constructed out of thin plywood which is cut into a teardrop shape, with egg-shaped grips on both sides and a strap on the left hand side. The sensors themselves are inset on a thin piece of foam board, which is helpful for rapid prototyping of the buttons and tine layout. The two pieces of plywood are fastened to each other by means of a rotary pot to measure rotational displacement (see inter-hand movement below). The teardrop shape, in addition to aesthetic considerations, offers the player visual feedback as to the amount of rotation between the two halves.

4.1 The Tines

The current prototype features 8 piezo tines, using DT-series piezo film made by Measurement Specialties, Inc. The tines are approximately 0.5mm thick, and are rated to have frequency response up to 50khz [11]. A comparison of the frequency response of one of the tines being plucked to that of a damped guitar high E string can be seen in figure 5.

For the physical model itself, we are experimenting with

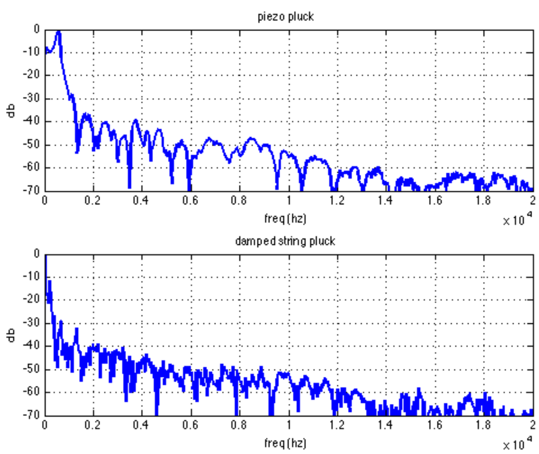

Figure 5:
Frequency Response of Piezo Tine Pluck (top) vs Damped Guitar E String (bottom)

different amounts of complexity but we have found that, even using a primitive single waveguide model [7], the tines produce a very realistic and playable virtual string. In our current setup, the pluck signal goes through a hardware interface and into a computer running Max/MSP [12], where the string model has been compiled into a Max/MSP external object.

For added expressivity and realism, we also wanted the Kalichord to distinguish whether the finger was plucking or merely resting on its tine, so that we could dampen the virtual string in the latter case. At first, we tried to get this data directly (through low-pass filtering the tine signal), but this often produced a false positive (occasionally sensing a touch after the tine had been released). So instead, we have attached small force-sensing resistors (FSRs) to the base of each tine, which works much more reliably. Hopefully in future designs we will be able to eliminate the FSRs.

Figure 6: Innards with Arduino and Rotary Pot (left) Tines, FSR and Mode Button (right)

4.2 Bass Buttons

The bass buttons are momentary switches arranged underneath the left thumb and fingers. In the current prototype, there are 12 bass control buttons located under the thumb of the left hand, and 9 buttons under the other four fingers. Two of the buttons are raised for tangible navigation. In the current prototype, the button signals are sent into Max/MSP through an Arduino microcontroller [13], and the bass tones are created using additive synthesis of a few simple oscillators.

4.3 Inter-Hand Movement

The Kalichord also registers rotational motion between the two hands by means of a rotary pot (figure 6, left) connecting the two halves. The rotational position is fed into Max/MSP via the Arduino (figure 6, left). This data can be used for expressive control such as pitchbend, volume, or vibrato, as well as for changing the note values of the tines.

4.4 Mode Button

There is one large button positioned under the thumb of the right hand (figure 6, right). This button is used for toggling through different modes of play or engaging certain effects, such as pitch bend or output distortion.

4.5 Modes of Play

We are still experimenting with different ways of mapping notes to individual tines. One method that has been effective is what we call "bass-control mode." In bass control mode, chords are determined by the left hand thumb buttons. The thumb buttons then have two functions – they play the tonic of the chord, and also change the notes of the rest of the bass buttons and tines to adhere to the new chord. In this way, any bass line that begins with the tonic will be extremely easy to play; you just pres the thumb button pertaining to the chord you want, and the rest of the bass buttons and the tines transpose themselves.

Bass control mode would be helpful for vocal accompaniment or rhythmic support; playing non-chordal melodies, however, would be difficult in bass control mode, since you can only play notes that are in the current chord. For more melodic play you could then use what we call slide control mode, where the notes of the tines change as you rotate the two sides in relation to each other, as though you were moving your hand up across the various strings of a harp. This mode is substantially harder to play than bass control mode, and we are still working on ways to make it more intuitive.

5. Website

We have created a website with information, pictures and video of the Kalichord at:

http://www.dannymo.com/kalichord

6. Results

6.1 Realism and Expressiveness of the Tine-Strings

We plan to perform rigorous user testing of the Kalichord, but so far, informal test results have been very encouraging. A number of guitarists have played the Kalichord and reported that the tine plucking felt very similar to plucking real strings. In addition to tactile similarities between a tine and a string (they both provide force that varies linearly with displacement [14]), this may also be due to the range of timbres available when plucking the tines. By subtly changing some of the characteristics of the pluck such as the position of the finger on the tine, the amount of fingernail used, or the speed of release, the player is able to excite a large variety of frequencies. Figure 7 shows the frequency profile of two separate plucks from the same tine (just the pluck, no string response), and you can clearly see how different

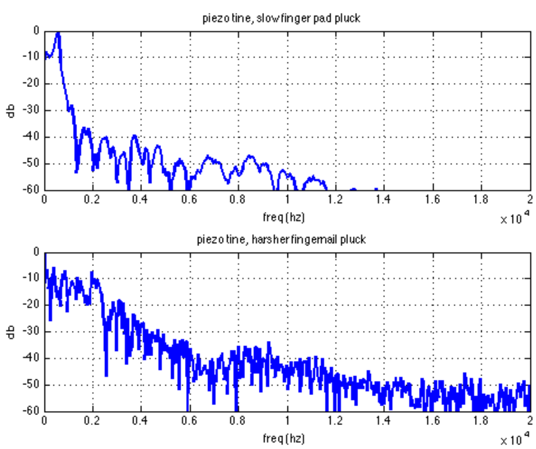

Figure 7:
Frequency Response Of Two Differing Tine Plucks.

they are, especially in the 200hz-1khz range. After playing for a minute or two, one musician reported that he had learned the characteristics of the tine response and adjusted his playing accordingly. This adjustment may also contribute to the perceived realism of the tine strings.

7. Conclusion/Future Work

Our work on the Kalichord is by no means finished. We have shown that using tines as an excitation signal for a string model gives us a high level of realism and expressiveness. Additionally, we have demonstrated a way of exploiting the tine-string form factor to devise new ways of playing plucked string instruments. We plan to continue experimenting with different note and effect mappings as well as with with more advanced physical models in order to increase realism. We hope that our techniques will help others create even more interesting and expressive musical interfaces.

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