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Creating Sustained Tones with the Cicada's Rapid Sequential Buckling Mechanism

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ABSTRACT

The cicada uses a rapid sequence of buckling ribs to initiate and sustain vibrations in its tymbal plate (the primary mechanical resonator in the cicada's sound production system). The tymbalimba, a music controller based on this same mechanism, has a row of 4 convex aluminum ribs (as on the cicada's tymbal) arranged much like the keys on a calimba. Each rib is spring loaded and capable of snapping down into a V-shape (a motion referred to as *buckling*), under the downward force of the user's finger. This energy generated by the buckling motion is measured by an accelerometer located under each rib and used as the input to a physical model.

Keywords

Bioacoustics, Physical Modeling, Controllers, Cicada, Buckling mechanism.

INTRODUCTION

Though many bioacoustic systems are similar to those found in musical acoustics [4], the cicada's use of a sequence of rapidly buckling ribs to excite and sustain tones is rather unique. Neither the *buckling* mechanism itselt, nor the use of discrete impulses to sustain musical tones, seem to be used by any traditional musical instruments. Musical instruments generally require the player to supply continuous energy to sustain a tone, as in the continuous motion of the arm while bowing a string instrument, or the continous blowing required to sustain a note on a wind instrument. Discrete excitations mechanisms such as plucking or striking generally produce tones that decay after a period of time.

In this research, a music controller based on the cicada's buckling mechanism was developed, so that its potential as a musical instrument could be explored. It provides a mechanical user interface to an already existing physical model of the cicada's sound production mechanism [4], allowing the user to manipulate the computer model's parameters in a meaningful and intuitive way.

A public demonstration of the device showed that people were captivated by the the responsiveness of the mechanism itself (as this was an early stage in the device, there was still no sound). The way the spring loaded mechanism caused the ribs to bounce back up at the user everytime they were buckled, created an animated excitement in some users and seemed to prove the importance of physical stimuli in user intefaces (something which is, perhaps, too often overlooked).

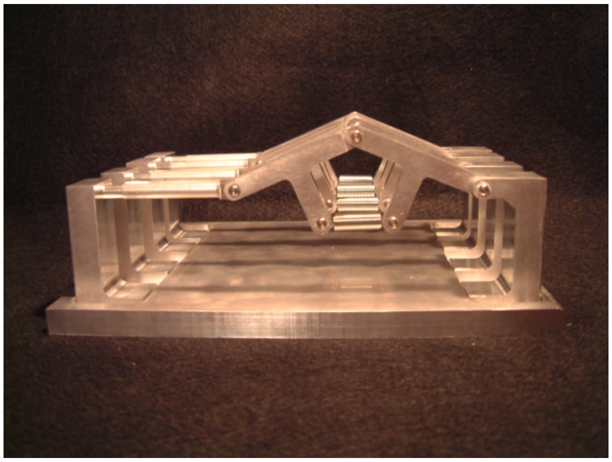

Figure 1: The tymbalimba

This paper will briefly review the cicada's rapid sequential buckling mechanism (which is used to excite the primary mechanical resonator of the sound production system), and discusses how this mechanism is incorporated in the development of a musical controller for an existing physical model of the cicada [4]. Other issues, such as interfacing the mechanical model to the physical model, will also be discussed.

THE CICADA'S RAPID SEQUENTIAL BUCKLING MECHANISM

The cicada uses a rapid sequence of buckling ribs to excite the primary resonator of its sound producing mechanism [1]. *Buckling* is a nonlinear phenomenon that results when an inward force applied to a convex form causes it to spring into a concave form [3] (see fig 2).

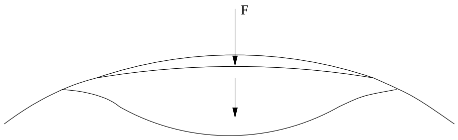

Figure 2: Inward buckling of a tymbal rib

When the force is no longer present, as is the case when the muscle relaxes, the rib is free to spring back to its original shape, ready to be buckled again.

The cicada's primary sound production organ, the tymbal, is equipped with a series of convex ribs that collapse under the force of a contracting muscle [3]. The tymbal plate, the primary resonator, is immediately set into vibration after the first buckling rib. Each subsequent buckling sustains the vibration of the plate, allowing the cicada to produce a sustained tone.

THE MECHANICAL MODEL

The tymbalimba, like the cicada's tymbal, consists of 4 convex aluminum ribs arranged in a sequence, much like the keys on a calimba, so that each rib fits comfortably under the hand's fingers (the spacing between the ribs is adjustable to suit the user).

When a user applies a sufficient downward force to a rib, it buckles (see figure 3). The energy signal generated by this motion will depend on variables such as the force used and the speed of the finger's motion. As in the case of the tymbal ribs, when the user removes his/her finger, the model's rib will spring back to its original shape.

Depending on the species of Cicada, the rate of muscle contractions can occur as frequently as 200 Hz. Of course, the neurogenically initiated muscular contractions of the cicada give it quite an advantage over a human. It would be absurd to expect a human to buckle the mechanical ribs as quickly as a cicada – it certainly wouldn't be long before the pain of repetitive strain injuries was felt. The mechanical controller therefore, aims to capture the energy generated by the buckling of the first rib – based on this signal, the sequence can be generated by the physical model. This solution allows a human to experiment with a unique sound producing mechanism, and the unique sound that results.

Since there are 4 ribs to buckle on the controller, the user does not have to repeat the buckling motion on the same rib (again, an ergonomic adjustment). Rather, the user wishes to initialize each buckling sequence more quickly, s/he can "drum" the fingers over all 4 ribs.

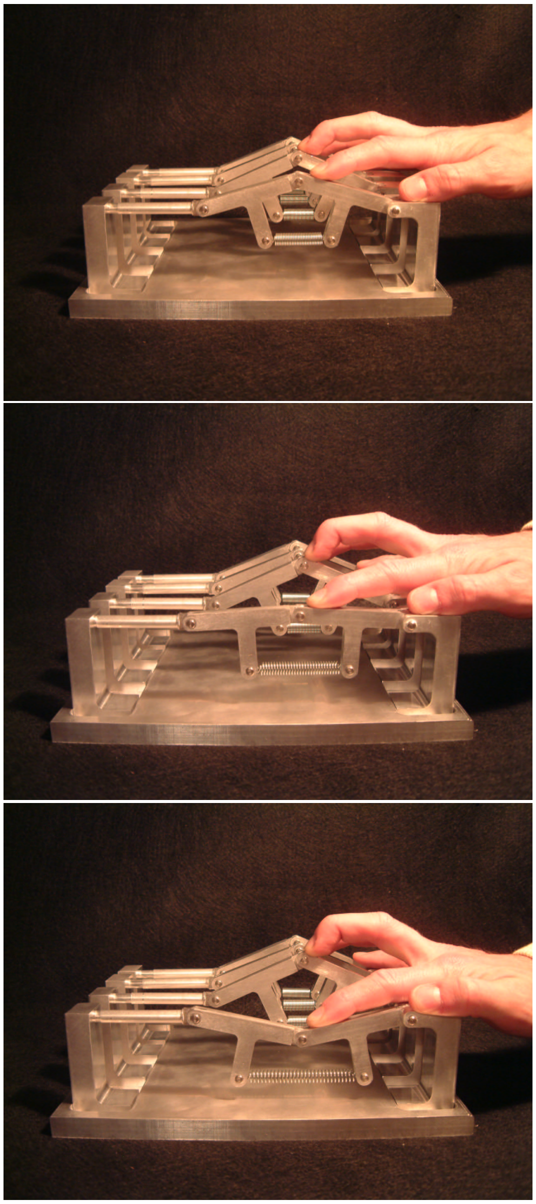

Figure 3: The controller's buckling motion

As the idea of the controller is to capture the buckling excitation mechanism itself, and not necessarily the ability of nature's finest virtuoso of this mechanism, the speed at which the user buckles the rib is left up to musical experimentation. What is important is that the user's single motion initiates a sequence of several energy impulse (generated by the physical model) that will allow the production of a sustained tone.

The user can change the signal generated by the buckling ribs, by varying the gesture of the attack (speed of motion or force used). The cicada changes the amount of energy released by changing the curvature of the ribs [2]. This also may be accomplished in the controller by changing the length of the bottom spring that holds the two parts of the rib in place. A shorter spring gives more curvature to the rib, making it more difficult to buckle. As a result, more energy will be released by the first rib and a greater number of ribs will buckle in the sequence (by the physical model). This is, however, a decision that must be made before a performance, much in the same you decide upon certain reeds or strings before playing traditional musical instruments.

INTERFACING TO THE PHYSICAL MODEL

What is measured by the controller is not the force input of the user, but rather the energy produced by the ribs that are *buckled* by the user. Accelerometers under each rib measure the energy generated by the buckling motion and, after passing through a signal conditioning circuit, provide an input excitation signal to the physical model. Based on this signal, the computer model will then determine the resulting buckling sequence.

The controller provides a more accurate input signal to the physical model than the arbitrary impulse signals previously being used [4] and, because the user is playing a real mechanical system, s/he is not denied haptic information important when playing a musical instrument.

Physical modeling synthesis tends to be extremely parameter-rich, often requiring too much attention to individial variables to be suitable for real-time performance. The previously developed physical model of the cicada ([4]) suffered from this problem when determining the parameters of a rather complex system of buckling ribs. How many ribs should buckle? What is the rate of buckling? What is the rate of muscle contractions (the time before re-starting the sequence of buckling ribs)? What is the energy difference between the IN and OUT buckling cycle or between the buckling of the first and last rib?

Just as the cicada varies each of these parameters during vocalization, so should the user be able to manipulate, in real-time, all the factors that determine the physical model's sound. Of course, it is impossible to be aware of, let alone control, so many individual parameters when playing any musical instrument (electronic or acoustic). And since it is generally not desirable to remove functionality from a physical model by eliminating some of its parameters (just to make it more controllable), it would be useful if these parameters could be obtained from functions representing one single action or gesture which the user could learn to do in various ways to produce different results.

By buckling one rib, the user uses one motion to produce a signal that is sent to the physical model. From this input signal, the physical model can derive many of its parameter values without subjecting the user to the daunting task of tweaking a myriad of knobs and buttons. From one gesture, the model obtains information about the envelope of the impulse (which effects both timbre and volume in the sound), the number of ribs that will buckle in the sequence (which is derived from the amount of energy in the signal, and, since each rib can be mapped to a pitch, frequency information can also be obtained. Since the parameters are determined by one motion of the user, they will change only as the motion changes. With time and practice, the user will eventually learn how varying the motion changes the quality of the sustained tones of the systhesizer, and will be much more successful in playing the instrumnet.

BUILDING THE MODEL

As much of the work in this project involved designing and building the mechanical controller, a section is included describing the methods used.

Machining Methods

The parts of the model were machined from aluminum (6061-T6) on a CNC mill at Stanford University's Product Realization Lab (PRL). Fixturing of the ribs (T-parts) was done with each part attached to a block of aluminum via socket-cap screws. Each screw was placed at each of the 3 tips of the T-parts, taking advantage of the need for holes in these positions to place the axial shafts.

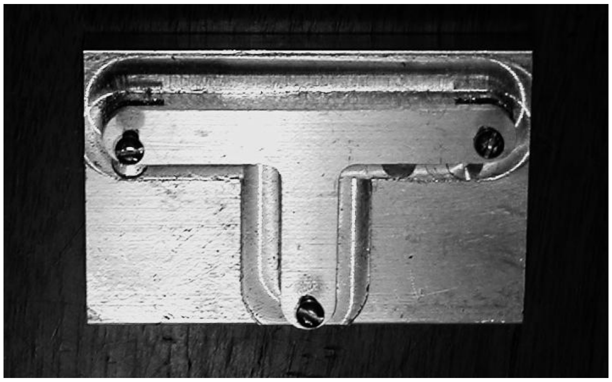

Figure 4: Fixturing the T-part for CNC machining

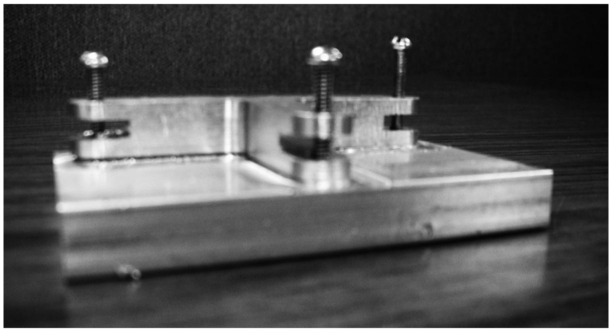

Figure 5: A side view of the T-part when fixtured for CNC machining

Obtaining the Signal from the Buckling Ribs

Accelerometers are placed under the T-parts, with the wiring hidden in thin channels to reduce their visability. Since it is only the envelope of the signal that is needed (scaling will take place in the computer), the accelerometers provide the desired signal generated by the buckling ribs, with very little need of additional signal conditioning.

The output of each of the 4 accelerometers is sampled using an analog to digital converter (MAX1270) before being sent on its own channel to the Basic Stamp microcontroller. The output of the Basic Stamp is then sent through the computer's serial port and received through a Pd [5] serial obeject. This *buckling* signal is then available as input to the physical model.

FUTURE WORK

An addition to the instrument, currently in progress, will allow the user to change the sounding pitch with the right hand, while controlling the buckling mechanism with the left. It is an extension of the base plate, and will contain 4 linear force sensing resistors (FSR) (one for each octave). Specially formed grooves in the plate will allow the user to easily locate the tempered placement of pitches on the FSR, while still permitting the finger to slide between the them.

Future work may also include creating different sizes of the controller. For example, it may be interesting to create a scaled down version so that it fits easily in one hand, and buckling occurs when one “makes a fist”.

CONCLUSION

The tymbalimba goes beyond simple on-off triggering devices. Measuring the energy generated by the mechanical controller, provides the physical model of the cicada with an input signal that accurately represents the user's gestures, as well as the buckling motion of the ribs. Not only does this eliminate the incumbrance of controlling the countless individual parameters normally associated with physical models, but it allows the user the satisfaction of playing a responsive haptic interface – and hearing the results of the intriguing sustained tones of the cicada's vocalization.

ACKNOWLEDGEMENTS

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