Exertion Instruments

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Abstract
In this paper we introduce a new family of musical instruments, which, like traditional acoustic instruments such as guitar and

drums, derive their acoustic energy in direct proportion to the exertion of the player's muscles, yet have electric or electronic oscillators for sound generation. The motivation and advantages of this technique are explained, along with an evaluation of some initial designs.

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ACM Classification Keywords

H5.5. Information interfaces and presentation (e.g., HCI): Sound and Music Computing.

Introduction

A few critical characteristics divide the world of traditional acoustic instruments from the vast majority of electronic and computer instruments. Namely, accessibility/immediacy and portability. Acoustic instruments can be taken places electronic ones can not, such as through the neighborhood pubs on street corners in Rio. They are lower maintenance than electronic ones. At the most, they require tuning or occasionally strings, while digital instruments may require batteries, disk space, upgrades, configuration, storage media, file conversion utilities and in some cases even subscriptions. Finally, most electronic instruments require additional components to function, such as an amplifier, power source, additional software components or a sequencer.

Yet electronic instruments are very popular for clear reasons: They can make completely different timbres, ones which are basically impossible to create with acoustic means. Also, these timbres are much more flexible.

Accessibility and Immediacy

Perhaps everyone has at one point in their lives attempted to play a traditional musical instrument. For example, while visiting a friend, one might spot a guitar resting on a couch and strum it. In contrast to electronic instruments, such instruments are always available to play. A typical music synthesizer requires a power source and an amplifier to be connected before it can be played. Furthermore, the proper patch, volumes, etc. must be configured. This, along with the possible commitment to download and install, reduces the immediacy and accessibility of electronic instruments, inhibiting curious people from trying them out. Therefore, any exertion instrument should produce sound the moment it is touched.

Portability - Physical Form

Most acoustic instruments are, unlike electronic ones, designed to be played while being carried. Usually they are small enough to be carried by the hands and arms, such as a trumpet or fiddle. When they are a little bigger, or require two hands, straps can hold them to the player's body, such as in the case of drums and xylophones.

A brief examination of electronic instruments such as laptop software, the theremin, drum machines and keyboard synthesizers reveals they are not designed with transportability in mind. Most are designed for "tabletop" use. There are some exceptions to the physical form rule, such as the Keytar and digital saxophones, etc. These instrument's designs extend their transportability, but they are still not qualified to be exertion instruments. Specifically, they require power sources which diminish over time.

Portability - Local Power Generation

The power source is the key distinction between conventional instruments and exertion instruments. In order to create electronic sounds, whether transistorized, or simply electric, a current source is necessary. In most cases, power is supplied from AC mains or batteries. Connections to AC mains require cables, which severely restrict mobility. Batteries present two key problems: recharging and weight. While weight can be addressed with modern technology, such as dense lithium cells, there is no escaping the recharge requirement. In practical terms, recharging means a musician playing an electronic instrument must stop to recharge or exchange batteries from time to time. Recharging generally means a side trip to an AC mains source and downtime. Such interruptions put a damper on the flow of a musical performance. For example, a musician with battery-powered instruments might not be able to take part in a spontaneous, late-night jam, nor travel for long distances.

Exertion - Modes of Playing

It is common for acoustic instruments to have one basic mode of play. On top of that, musicians tend to discover quirks which lead to enhanced modes of expression. For example, bowing a violin while fingering its neck is its fundamental mode of operation.

> But violinists don't just want to play long, steady bow strokes. For musical purposes a wide variety of different bowing gestures are used, such as martelé (hammered bowing with a sudden release) and spiccato (rapid detached notes with the bow bouncing off the strings). [1]

Typical digital instruments can not help but have hard limits on their sound generation architecture which can not approach what physical instruments can do. For example, keyboard keys can only be moved in one dimension. Velocity and aftertouch can further the expression, but any movements not designed into the instrument from the start can not be expressed through the instrument. Furthermore, the audio synthesis routines in digital instruments are designed for stable operation within a range.

Exertion - Physical

In addition to having quirky physical techniques which typical electronic instruments can hardly replicate, every acoustic instrument behaves differently at its physical limits. For example, while a musician may easily reach the limit of the velocity detector on a synthesizer keyboard, an instrument such as accordion or trumpet can always be pushed to play a little louder. Of course, at some point, both the instrument and the player risk physical damage, from broken strings and ripped drum heads to repetitive strain injuries and blisters. Therefore, a certain kind of tension exists for acoustic players: a tradeoff between volume and damage.

With electronic instruments that use power supplies like batteries and AC mains, there is always a steady reserve of electrical power available. Without really intending to, it is easy to make outrageously loud sounds, resulting in a potentially large disconnection between one's movements and the results of one's actions. This principle is addressed in the artwork "Blendie" by Kelly Dobson.[2] In her piece, the power on switch of a powerful appliance - a kitchen blender - is replaced with a circuit that detects loud growling sounds. One interpretation of this piece is that in order to make a large movement, one must have serious intentions.

Exertion instruments address a similar point. Instead of carrying a large reserve of power in the form of batteries, their power must be generated on the spot. This means that if a player wants to create louder sound, he or she must exert harder. This exertion makes it impossible to create a perpetually loud sound as noise musicians do. The player must reserve strength for those moments that deserve it. It also means that the body movements of the musician follow their sound more closely.

Experiments

Now that the requirements and strong points of exertion instruments have been described, the results of some initial designs can be reported. For this paper, two exertion instruments were constructed and played informally for various lengths of time by approximately 20 people. The first instrument employs a stepper motor and a speaker to form an oscillator. The second uses a hand cranked generator to drive a microcontroller-based tone generator and amplifier.

Experiment #1 - Cogging

The first instrument uses an electromechanical effect particular to stepper motors called "cogging," The details of stepper motors need not be described here, but they are well documented in sources like [3]. What is relevant about the stepper motor is that turning its shaft results in the generation of small amounts of electricity at its terminals. These bursts of electricity occur in short, regularly repeated intervals and are large enough to drive a medium-sized speaker directly.

In experiment #1, a stepper motor's terminals were connected directly to the terminals of a discarded household stereo speaker (diameter = 8 inches. Impedance = 8 Ohms). In order to facilitate turning the stepper motor's shaft, a simple aluminum crank was fastened to it. The result is an instrument which can create low, "wumping" sounds at a significant volume. The volume and pitch are directly proportional to the force applied to the crank. The observed pitch range was approximately 60-350 Hz.

Exertion instrument #1 has no specific means of pitch generation. It was up to players to determine how to make it musical. Several modes emerged:

Experiment #1 - Cogging - Steady pitch

Rotating the crank at 2 rotations per second should produce a 150 Hz sound. In practice, the pitch was found to flutter quite a bit. It was difficult to maintain a steady pitch, but sometimes possible. Perhaps with more practice and a good ear, steady pitches will be more commonplace.

Experiment #1 - Cogging - Kick Drum

A simple whack of the instrument's crank results in a waveform that goes from high pitch to low pitch as it naturally slows down. This is very similar to the synthesis technique of kick drums used by drum machines such as the Roland TR-909. With a little practice, the parameters of the sound, such as initial pitch and decay could be controlled. One problem with this technique is that the crank ends up in a random position after the whack. It was somewhat controllable with practice, though not entirely.

Experiment #1 - Cogging - Tabla

Turning the crank while holding it allows one to have more precise pitch and volume control than the kick drum method. It is easy to create short bursts of tone that have only a slight variation in pitch. Holding the crank lets the player play several different tones in rhythmic succession. An observer remarked that this sounds like a tabla.

Experiment #1 - Cogging - Snare

In an effort to keep the crank in a predictable position following the kick drum technique, a two handed technique was adopted. One hand whacks the crank, while a second hand is set up to stop it after e.g. 1/4 rotation. This results in a brief, higher-pitched tone, much like the drum head on a snare. There was also an interesting surprise: the percussive slap of the aluminum crank against the "stopping hand" created a slightly metallic crash sound which resonates through the speaker's body! The combination of this metallic crash with the electromechanical tone created a snare-like sound.

Experiment #1 - Variation

A simple modification was made to exertion instrument #1. An electrical transformer of turns ratio 10:1 was placed between the stepper motor and the speaker. The result was that the overall pitch range was higher and louder. The crank was easier to turn. This suggests that a small array of transformers could switched in and out of the circuit to vary the impedance and tonal range of the instrument, just like the valves on a trumpet.

Experiment #1 - Conclusions

We are very excited by the results of exertion instrument #1. The volume is acceptably loud and it has an intriguing range of usable sounds. Its timbre is warm and deep, like a bassoon, tuba or tan tan. It would work best in conjunction with other instruments. It can be played all night without batteries and is light enough to be carried around the shoulders. Varying degrees of exertion produced a variety of expression. It was also very easy to build, with parts that will be available for many years, as opposed to microelectronics, which are subject to market availability.

One of its biggest issues was the lack of precise pitch control. This placed it more in the category of percussive instrument rather than tonal instrument. Perhaps some pitch regulation means can be devised, allowing it to be used in a harmonic context. Finally, it was observed that the mass/inertia, shape and length of the crank can be significant factors in the sound.

Experiment #2 - Hand Cranked Microelectronic Synth

The second instrument used a hand-cranked generator to supply power to a microcontroller and an amplifier. It may be seen as "less pure" than exertion instrument #1 because the sound comes not from the electromechanical interface but from Digital Signal Processing (DSP) which is typical of electronic instruments. Nevertheless, it adheres to the requirements of an exertion instrument. The crank generates all of the power for the microcontroller and the amplifier. It should be noted though, that it does not function as a typical hand-cranked emergency radio/flashlight. Cranking does not recharge an internal battery. Instead, it generates power instantaneously. The volume of sound at any instant is directly proportional the energy the user puts into it.

The hand crank generates power at approximately 0 to 5 Volts, depending on how hard and quickly it spins. When the crank is motionless, the microcontroller can not run and the instrument is silent. When the generator voltage reaches approximately 2.5 Voltages, the microcontroller is able to run a simple program that outputs a tone. This is still not enough to be audible though, because the amplifier does not have enough power to run. Therefore, the player must crank a little bit faster. When the voltage reaches about 3.0 Volts, the sound becomes faintly audible. It is much louder at 5.0 Volts.

The player has *nearly* instantaneous control of the volume at any time. The modifier "nearly" is used because the volume ramp is dependent on the player's ability to quickly change cranking speed. Since the crank is attached to a series of gears that increase the gear ratio, there is a noticeable amount of inertia. Since the volume can not change as quickly as a typical electronic instruments' knobs and its volume depends on a complex physical system, it is tricky to make quick ramps from zero to full in volume and much easier to make long decaying volume ramps. These pseudo-artificial constraints made the amplitude envelope and therefore the overall sound of the instrument distinct.

In this initial experiment, the DSP details were simple: a series of four binary pushbuttons selected a tone from a chromatic scale played as a square wave.

Experiment #1 - Observations

We were pleased that the crank was sufficient to power the microcontroller and the amplifier/speaker. Many people wished it was louder, however. Some technically savvy players suggested simple electrical modifications that could increase the volume. For example, bypassing the generator's voltage-regulation. Also, an H-bridge could be employed instead of the simple one transistor amplifier. Another shortcoming of the device was the sound of the crank and its gearing competing with the speaker's sound. Similar to exertion instrument #1, the sound of the crank resonated through the body, only in a less pleasing way.

Perhaps because of the amplitude envelopes and relatively reedy sound, many listeners described the instrument as sounding like an electronic hurdy-gurdy. In order to truly demonstrate the advantages of exertion instruments, this one requires more tonal variation.

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Citations
[1] Woodhouse, J. and Galluzzo, PM. "Why is the Violin So Hard to Play?" [http://plus.maths.org/issue31/features/woodhouse/index.html].

[2] Dobson, Kelly. "Blendie." http://web.media.mit.edu/~monster/blendie/

[3] Acarnel, Paul. Stepping Motors: A Guide to Theory and Practice (Control Engineering). Institution of Electrical Engineers; 4 edition (December 2002).