HYPERACOUSTIC INSTRUMENTS: COMPUTER-CONTROLLED INSTRUMENTS THAT ARE NOT ELECTROPHONES.

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ABSTRACT

This paper describes a musical instrument consisting of a physical process that acoustically generates sound from the material world (i.e. sound derived from matter such as solid, liquid, gas, or plasma) which is modified by a secondary input from the informatic world. This informatic input selects attributes such as the frequency range of the musical note being sounded, while the acoustic process is kept in close contact with the user, to ensure a high degree of expressivity. In one example, ice skates with acoustic pickups are used to play music while the skater simultaneously controls a bandpass filter with a hand-held keyer and wearable computer. Each skate works much like the bow on a violin, allowing the player to hit, scrape, rub, or "bow", the ice in various ways to create a wide variety of musical textures. Additionally the player can select sound samples on a per-note basis and then "scratch" out a melody or harmony (playing multiple samples at once) on the ice on the rink like a team of Disk Jockeys (DJs) working together to "scratch" an array of vinyl records. Because the grooves on an ice rink are made by the player in a freeform fashion, there is much more room for variations in musical timbres and textures than with the fixed grooves of a record.

Rather than merely using the keyer to trigger musical notes through MIDI note on/note off commands, we create acoustic sound through a physical process such as skating, and then turn those physical sounds into musical notes with the handheld keyer that functions as a modifier input. This combination combines the expressivity of non-electrophonic musical instruments like the violin with the flexibility of electrophones like the sound synthesizer.

As a further contribution of the paper, a general taxonomy of acoustic transducers and a link to physical organology is provided, in which the top-level of the taxonomy is the state-of-matter in which the transducer operates.

Index Terms— Hyperacoustic, pagophone, pagolin, hydraulophone, reustophone, poseidophone, idratmosphone, atmosphone, H2Orchestra, musikeyer, elementary organology

1. HYPERACOUSTIC SIGNAL PROCESSING

Unlike a hyperinstrument[1] in which position sensors, or the like, ADD synthetic sounds to an acoustic instrument, hyperacoustic instruments use position sensors, or the like, to MULTIPLICATIVELY combine these. Most notably, hyperacoustic instruments use a synthetic input to modify an acoustically generated sound. See Figures 1 and 2.

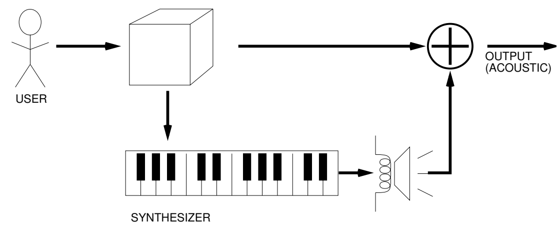

Fig. 1. *Hyperinstruments:* Acoustic signals are **added** to by synthetic signals. The user has control over physical process only.

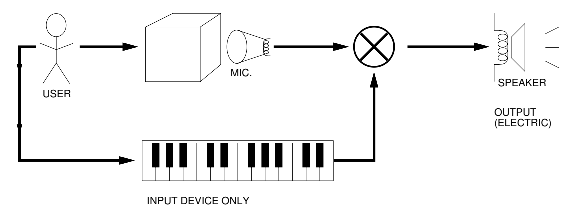

Fig. 2. *Hyperacoustic instruments:* Acoustic signals are **multiplied** or otherwise modulated by an additional controller, which serves as an extra input device for the user.

1.1. What is an acoustic sound source?

Organologists and ethnomusicologists often address fundamental philosophical questions regarding categorization of musical instruments in view of recent developments. Instruments are generally classified based on initial sound production mechanisms; for example, an electric guitar is still a chordophone, not an electrophone, even though electricity (and now computation, i.e. digital effects pedals, etc.) is involved extensively further along the sound production path [2][3].

Hyperacoustic processing of audio signals relies on an acoustic sound source—ie. one which falls outside the "electrophones" category. In particular, we focus on acoustic signals from real-life physical processes in which the sound-producing medium is closely linked with the user-interface, in terms of controllability and tactility.

1.2. Physiphones and states-of-matter

A current trend in musical interfaces has been to expand versatililty and generality by separating user interfaces from their corresponding sound-producing media. Examples include the piano, harpsichord, and sound synthesizer, which often have a similar user interface that is quite separate from the harp or any physical process. The mechanization and consistency of user-interface allows more intricate and complex pieces to be played by a single person.

This paper identifies an opposite trend in musical interface design inspired by instruments such as the harp (when the strings are directly plucked by the user), the acoustic or electric guitar, the tin whistle, and the Neanderthal flute. These instruments have a directness of user-interface, where the musician is in direct physical contact with the sound-producing medium.

We propose the invention of new instruments that are designed to have this expressive intimacy, while also allowing for their high degree of virtuosity.

Previous examples included the poseidophone, an instrument made from an array of ripple tanks, each tuned for a particular note [4], and the hydraulophone, an instrument in which sound is produced by pressurized hydraulic fluid that is in direct physical contact with the fingers of the player [5].

To better understand and contextualize some of these new primordial user interfaces, a broader concept of musical instrument classification has recently been proposed that considers the state-of-matter of the sound production medium as well as the state-of-matter of the user-interface [4].

2. THE PAGOPHONE

In the early 1980s, author S. Mann formed the concept of an "H_2Orchestra" in which dihydrogen monoxide (H_2O), in its various states of solid (ice), liquid (water), and gas (steam/vapour), as well as underwater plasma (fourth state-of-matter) were used to generate acoustic sound. These instruments represent all four "Elements": "Earth" (solid), "Water" (liquid); "Air" (gas); and "Fire" (plasma), using H_2O. The resulting four instruments are called the pagophone (Greek for "ice" and "sound" in the same way that "xylophone" is Greek for "wood sound"), the hydraulophone, the idratmosphone, and the plasmaphone. This paper further explores variations of the pagophone.

In one embodiment of the pagophone, variously lengthed bars made of ice are struck (see Fig. 3), and the sound is amplified by a pickup in each bar, or one for all bars. The pickups can also be connected to bandpass filters, a separate filter for each note, to improve the sound.

In other versions there are only 1 or 2 filters for 1 or 2 sticks, with input from a computer-vision idioscope [6] to determine which bar is struck.

In another embodiment of the pagophone, there is only one piece of ice which sounds different depending on geospatial or other input data.

In one embodiment, the pagophone is "played" on a skating rink (the ice that makes the sound) with skates (or, equivalently with skis on a ski hill, or with a toboggan, making sound from snow), each skate fitted with a pickup, passed through a wearable computer to a wearable amplifier and speakers. We call this a "pagolin" to draw the analogy of the skates to violin bows. In one version the pagist (pagophone player) uses a musikeyer to select the filter (the "note"), while putting expression into the foot scrape or other sound. One version has two keyers, and holds one in each hand.

Some but not all embodiments also use computer vision to do object location and adjust the pagophonic sound appropriately. For example, vision, radar, sonar, or lidar sensors or a combination of these watch the passing ice, and index through sampled audio files to create an effect similar to "scratching" a record.

3. VIRTUAL INSTRUMENTS WHICH PRESERVE THE ACOUSTICALITY AND TACTILITY OF A PHYSICAL SUBSTANCE

We recorded audio samples of ice-based acoustic sound from a pagophone, and encoded them into a SF2 soundfont. The soundfont (available at http://wearcam.org/pagophone/index.htm) enables us to replicate the sound of ice by playing on other media. For example, water can be made to sound like ice, and be given a playability akin to ice, in a virtual instrument which makes full use of the physical expressivity of the water, but simply translates the acoustic response to that of ice.

We have also created instruments which allow any kind of object in the real world to be played, and the means of playing to be shared across cyberspace — these instruments use acoustic pickups and body-worn computer vision, with a wireless internet connection to allow the exchange of virtual instruments from around the world [6].

4. KEYERS AS A CONTROL INPUT FOR HYPERACOUSTIC PROCESSING

If a handheld keyer is used, the array of blocks of ice can be replaced by just one block of ice, with the keyer used to select a musical note on the scale. In general, the keyer controls the type of hyperacoustic transformation to perform on the acoustic signal, and in particular, that transformation can gather content in the acoustic signal beyond the range of human hearing, and transform that full content into the range of human hearing, at the correct musical note. Ultrasonic and subsonic sound is used in order to gather the full expressive content that the user has control over in the physical sound-production process.

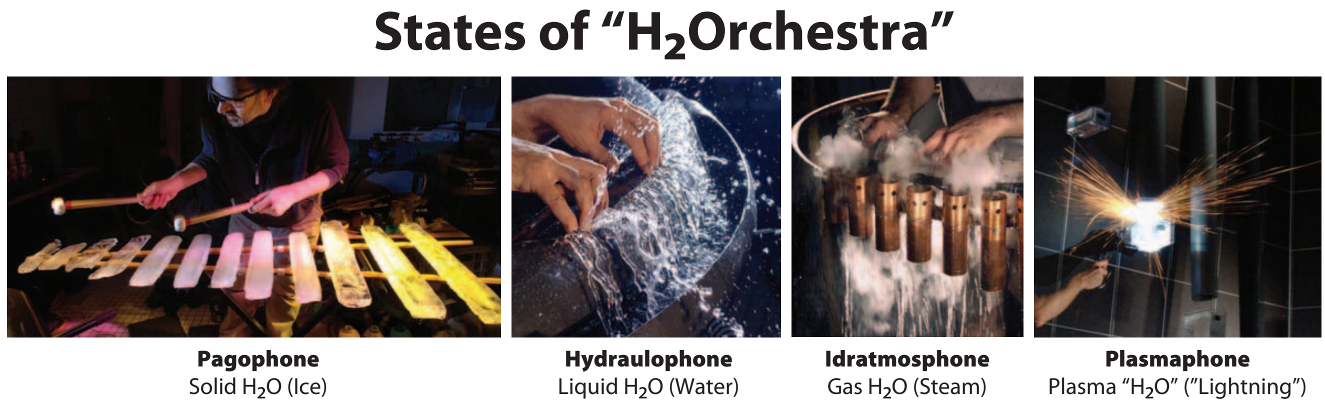

Fig. 3. Our H_2Orchestra uses musical instruments that make sound in each of the states-of-matter of H_2O (dihydrogen monoxide): Pagophone ("pago" is Greek for "ice" and "phone" is Greek for "sound") represents H_2O in its solid-state; Hydraulophone: a musical instrument that makes sound from matter (water) in its liquid state; Callioflute: a musical instrument that makes sound from matter (H_2O) in its gaseous (steam/vapor) state; Plasmaphone: a musical instrument that makes sound from underwater plasma generated by inserting special electrical probes into variously sized ripple tanks. Instruments that combine liquid and gas, or that will operate on either liquid or gas, are called reustophones.

5. MUSIKEYER

We propose the combination of two new musical instruments, the musikeyer, a handheld instrument that can be played while walking or jogging, and the physiphone, an instrument that is played from real-world physical processes.

The musikeyer is a simple portable computing device, with input and output that can be operated while walking, jogging, or waiting in line.

The device is a portable music player, that allows the user to play and compose music while standing or walking.

Keyers more generally can be extended to visual body-borne computing, where the user has the keyer input device in hand and uses it serendipitously while carrying on day-to-day activities. Keyer key-presses can be associated with audio, and computing with audio feedback (e.g. typing without looking at the screen).

For simplicity, the musikeyer device consists of a keyer with only 12 keys. The keys can be pressed individually to play single notes, or they can be pressed in combination to play chords. The single notes comprise the A natural (minor) scale from A to A followed by sufficient notes to play a C major scale from C to C, a D dorian scale from D to D (songs like "What Shall We do With the Drunken Sailer", and "Scarborough Fair"), and an E phrygian scale from E to E (flamenco music, and the like is often played in phrygian mode).

For typing the first 12 letters of the alphabet, the individual notes correspond to these letters. For letters that are further in the alphabet, chords (simultaneous keypresses which would sound simultaneous musical notes) can be mapped to those letters. The 12 notes of the musikeyer can be expanded to type the full set of ASCII text characters and more.

6. ACOUSTIC SOUND FROM REAL-LIFE PHYSICAL PROCESSES

Rather than using a keyer to trigger musical notes through MIDI note on/note off commands, we create acoustic sound through physical processes from the material world (i.e. one of solid, liquid, gas, or plasma). Furthermore, the physical process generating the acoustic sound is kept in close contact with the user, to ensure a high degree of expressivity. That is, the handheld musikeyer is treated as a modifier input, or a control input, while most of the expressivity comes from the physical process. The physical process becomes the dominant user-interface.

We have explored various solid instruments, liquid instruments, and gas instruments — all utilizing acoustic physical processes to produce sound directly in a specific state of matter, in close contact and similarity to what the user touches to play the instrument. One example is the hydraulophone, an instrument in which sound is produced by pressurized hydraulic fluid that is in direct physical contact with the fingers of the player [4][5] [7] [6] .

7. COMBINING MUSIKEYER WITH PAGOPHONE

The pagophone and musickeyer were paired as input devices, as illustrated in Fig. 4. Here the skates were used as a friction idiophone in which sound is picked up by a geophone. The geophone is like a microphone, but designed to pick up vibrations in solid matter, as in:

1. geophone = "earth" = transducer for solid matter (some types of geophones are called "contact microphones")
2. hydrophone = "water" = transducer for liquid matter (sometimes called "underwater microphone")
3. microphone = "air" = transducer for gaseous matter.
4. ionophone = "fire" = transducer for plasma matter.

In the same way that an electric guitar is still a chordophone, even when run through various effects pedals, the ice-skate instrument functions as a friction idiophone; i.e. an acoustic instrument that's electrically modified.

The electrical modification takes the form of effects (filters) that are applied by way of the musikeyer.

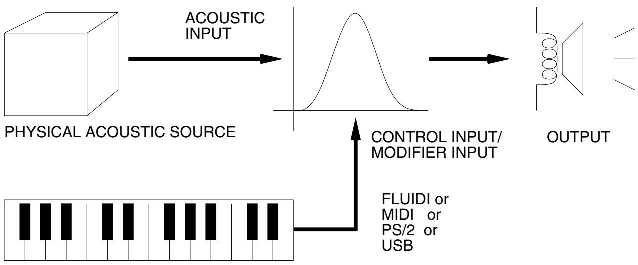

Fig. 4. Controllable hyperacoustic signal-processing scheme.

Fig. 5. Musikeyer-based wearable computer combined with ice-skates-based pagophone. See video online at: **http://wearcam.org/pagophone/index.htm**

8. GENERAL FRAMEWORK FOR HYPERACOUSTIC INSTRUMENTS

To make hyperacoustic instruments as expressive as possible, we wished to bring subsonic and ultrasonic sounds into the audible range by way of signal processing of the acoustically-generated signals. In a way similar to (but not the same as), superheterodyne radio reception, signals can be downshifted and upshifted by means of using an oscillator in the process of frequency-shifting and various forms of selective sound filtration. However, unlike what happens in a superheterodyne receiver, we prefer to scale frequencies logarithmically rather than linearly, in order to better match the frequency distribution of human perception. [5]

This digital signal processing is, in a general sense, a filtering operation, which may be highly nonlinear in certain situations. Our paper [6] describes nonlinear hyperacoustic processing which uses computer vision as a control input.

In hydraulophones, we have shifted ultra-low frequencies (of which a musician gains very detailed control [7]) into the audible range by means of oscillator-based filterbanks. In this way, the frequency band from 0 to 20 Hz in the subsonic range is brought into the audible range. [5]

Note that rather than triggering a sample or MIDI note as has been often done in computer music, we retained the acoustic property of the instrument by simply passing each of the parallel sound signals through a bank of nonlinear filters [5].

9. CONCLUSION

The "pagolin" is like a violin played by skates acting as the bow. A geophone attached to each skate is routed through a body-borne digital signal processing system, and then back into body-borne speakers. It has an input device called a musikeyer which controls the hyperacoustic processing functions. The musikeyer does not add acoustic content, nor does it remove acousticality of the instrument (ie. it does not cause the instrument to be musicologically classified as an electrophone [4]). This is an example of a hyperacoustic instrument which combines acoustic and expressively controllable physical processes with the versatility of computing.

10. REFERENCES

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