Natural Interfaces for Musical Expression: *Physiphones* and a physics-based organology

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ABSTRACT

This paper presents two main ideas:

(1) Various newly invented liquid-based or underwater musical instruments are proposed that function like wood**wind** instruments but use water instead of air. These "wood**water**" instruments expand the space of known instruments to include all three states of matter: solid (strings, percussion); liquid (the proposed instruments); and gas (brass and woodwinds). Instruments that use the fourth state of matter (plasma) are also proposed.

(2) Although the current trend in musical interfaces has been to expand versatililty and generality by separating the interface from the sound-producing medium, this paper identifies an opposite trend in musical interface design inspired by instruments such as the harp, the acoustic or electric guitar, the tin whistle, and the Neanderthal flute, that have a directness of user-interface, where the fingers of the musician are in direct physical contact with the sound-producing medium. The newly invented instruments are thus designed to have this sensually tempting intimacy not be lost behind layers of abstraction, while also allowing for the high degree of virtuosity. Examples presented include the poseidophone, an instrument made from an array of ripple tanks, each tuned for a particular note, 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. Instruments based on these primordial media tend to fall outside existing classifications and taxonomies of known musical instruments which only consider instruments that make sound with solid or gaseous states of matter. To better understand and contextualize some of the new primordial user interfaces, a broader concept of musical instrument classification is proposed that considers the states of matter of *both* the user-interface *and* the sound production medium.

Keywords

Hydraulophone, tangible user interface, ethnomusicology

1. SEPARATING TOUCH FROM SOUND

Modern technology has made it possible to separate the user-interface from the sound production mechanism of an instrument. For example, the harpsichord (and later the piano) is often regarded as an improvement over the harp, because it re-arranges the user interface (keyboard) in a more optimal manner than direct interaction with a harp. A series of mechanical levers, linkages, and other mechanisms allow the user-interface and sound production medium to each be separately optimized at opposite ends of an intricate chain of cause and effect.

Similarly, in the evolution of certain woodwind instruments, the addition of levers, linkages, and other mechanical aids allows the fingers of the musician to reach a larger number of finger holes than was possible with a simple flute like a penny whistle, shakuhachi, or recorder in which the fingers cover the finger holes directly. In fact there is a hierarchy of complexity ranging from a simple Japanese bamboo flute (shakuhachi) with only four finger holes, to a Western concert flute with mechanical levers and linkages to a larger number of holes, all the way up to a large pipe organ with mechanical, pneumatic, or electrical linkages to large numbers of wind-blown pipes.

The pipe organ is a very large woodwind instrument which often has a user interface that is quite separate from the sound producing medium. As a result of this separation, the user interface can be optimized for usability, and the sound production of the instrument can be separately optimized without the need for constraints such as keeping the pipes close enough together for a musican to be able to reach each pipe or each finger hole with his or her fingers. The pipe organ provides the musician with a wide variety of different woodwinds that are all mapped to the same user-interface, namely an array of keyboards and a pedalboard. By simply pulling out stops, drawknobs, or the like, a wide range of different ranks of organ pipes can be "connected" to the same standard keyboard user-interface. Many pipe organs also include "presets" that allow the musician to quickly reconfigure the instrument in various ways from one song to the next, or even within the same song. A wide variety of organ pipes have evolved to include woodwinds that sound like (i.e. "synthesize" the sounds of) flutes as well as brass instruments, stringed instruments, and other instruments. For example, some organ pipes are made long and slender and have a wooden "beard" near their mouths to emphasize higher harmonics, and some even have means to almost entirely suppress the fundamental. Intricate sets of holes, "beards", and intricate shaping of organ pipes allows the frequency spectrum to be altered in many ways to "synthesize" a tremendous range of different orchestral sounds. Some pipes are slightly detuned from one another so that they sound like stringed instruments or string ensembles when the appropriate ranks of pipes are played together.

This evolution toward separating the user-interface and sound-production medium reaches even greater heights with electronic keyboards where there is an essentially unlimited number of sounds that can all be mapped to the same user-interface, namely a piano-style keyboard.

The piano-style keyboard is not the only interface we need consider. For example, there exist a wide variety of wood-wind synths, guitar synths, and other devices that allow a musician operating one kind of user-interface to control other kinds of instruments.

Various kinds of hyper-instruments[1] and meta- instruments have also been proposed.

Modern improvements to user-interfaces allow one musician to play a larger more complex and intricate repetoire. The harpsichord or piano can be used to play very richly intricate compositions that a single musician would not be able to play on a harp. Similarly, an organist is often said to be "conducting" a whole "orchestra" of organ pipes. Some instruments, such as orchestrons, player-pianos, barrel organs, and elecronic keyboards can even play themselves, in whole or in part (i.e. partially automated music for a musician to play along with). For example, on many modern keyboard instruments a musician can select a "SONG", "STYLE", and "VOICE", set up a drum beat, start up an arpeggiator, and press only a small number of keys to get a relatively full sound that would have required a whole orchestra back in the old days before we had modern layers of abstraction between our user-interfaces and our sound-producing media.

1.1 Back to basics

Despite the many advantages of the separation of user-interface from sound-producing medium, a price we pay for this separation is a loss of pysicality. The harpsichord, for example, encloses and at least partially hides the harp both from touch and from view. Some indirect user-interfaces like the pipe-organ attempt to mitigate this problem by making some of the pipes visible as sculpture, but the audience still cannot see which pipe is sounding at any given time, and the musician does not get the same intimacy as with a tin whistle where her or she can touch and feel the air that is making the sound. Likewise the MIDI keyboard hides the orchestra inside layers of abstraction or computer chips that neither the musician nor the audience can touch, see, or directly experience in simple ways.

In this paper we wish to explore existing instruments and invent new ones that embody a simplistic physicality characterized by three guiding principles:

1. the user-interface is based, at least in part, on natural physical phenomena, preferably of a sensually primordial nature;
2. the sound-production medium is also based, at least in part, on natural physical phenomena; and
3. the interface phenomena (1) and sound production phenomena (2) are identical, or at least closely related.

Consider, for example, the oldest musical instrument in the world, the Neanderthal flute, made approximately 50,000 years ago, from the bone of a cave bear.

It has no levers, linkages, or keys. Instead, it was similar to a tin flute or penny whistle, in the sense of being played by placing the fingers in direct physical contact with the air in the pipe, making it easy, for example, to "bend" the pitch of notes by partial hole-covering.

Instruments like the Neanderthal flute, the tin flute, the harp (pre-harpsichord, i.e. just a raw harp), as well as the more modern guitar, embody this similar kind of simplicity in which the fingers of the musician are in direct physical contact with the sound producing media, i.e. the user-interface phenomena (1) and sound production phenomena (2) are the same.

2. ORGANOLOGY (ETHNOMUSICOLOGY)

In the context of understanding or inventing new musical instruments, it is useful to look at taxonomies of existing instruments from around the world.

Musical instruments are ordinarily classified into categories such as percussion instruments, stringed instruments, and wind instruments.

Victor-Charles Mahillon, curator of the collection of musical instruments at the Brussels Conservatory of Music, developed a system to precisely classify musical instruments based on the initial vibrating element in an instrument that made the initial sound. Mahillon's system was primarily for classifying western instruments used for classical music.

Ethnomusicologists Erich Moritz von Hornbostel and Curt Sachs expanded the Mahillon classification system to include all known instruments from around the world.

The Hornbostel-Sachs classification system, based on the Dewey Decimal Classification of library classification, identifies four top-level classifications by their Greek names:

1. **idiophone**: sound is produced by vibrations in the solid three dimensional body of an instrument. examples include xylophones, gongs, sticks, stones, and other three-dimensional vibrating objects;
2. **membranophone**: sound is produced by vibrations in a thin membrane. The membrane is principally two-dimensional in the sense that the thickness is small compared with the two dimensions of its surface;
3. **chordophone**: sound is produced by vibrations in a chord (string, wire, dawai, or similar long thin material) principally one-dimensional in the sense that the length is large compared to the two cross sectional dimensions.
4. **aerophone**: sound is produced by vibrating air;

with a fifth category, electronophones, later added. These categories are based on identifying the vibrating element that initially makes the sound in the instrument. This taxonomy of (1) solid volume; (2) solid plane; (3) solid line; or (4) gas, limits our thinking to only two states of matter: solid and gas.

This paper instead proposes a physics-based organology that considers both the input medium (interface) and the output medium (i.e. the sound production medium), with regards to their state of matter (solid, liquid, gas, or plasma).

2.1 Input-output mapping

Consider, as a top-level classification, the *state-of-matter* of the vibrating element that first makes sound. Aerophones, from the Greek words "phonos" = sounding, and "aero" = wind, remain as with the Hornbostel-Sachs mapping, but the other three-level categories now become subcategories

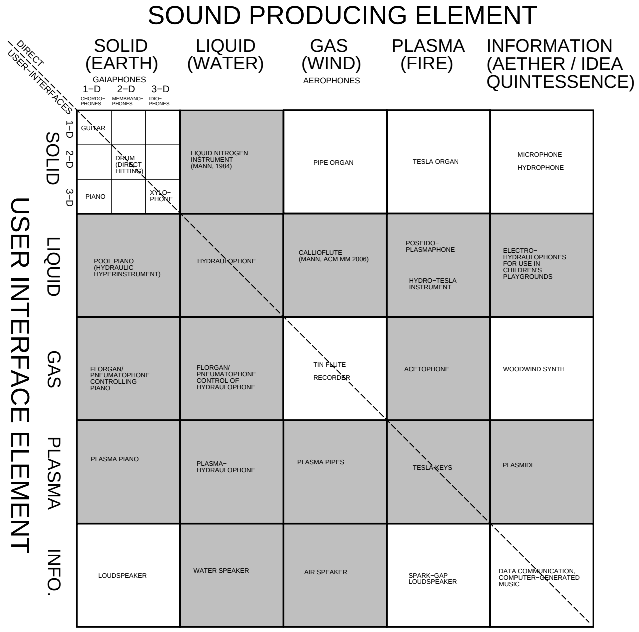

Figure 1: **A new organology based on physics:** Categorization of musical instruments by both their input (user-interface) and output (sound-producing mechanism) shows 16 newly defined categories (shaded) in each of which the author has invented at least one new instrument, along with 9 categories (unshaded) where instruments already existed. Those that fall on the diagonal are most desirable for direct user-interfaces.

under solid instruments. Solid instruments might be called "stereophones" from Greek "stereo" meaning "solid", but since "stereophone" already has another meaning, "Gaiaphone" is more appropriate (Greek godess of the earth — the Greeks used Earth, Water, Air, and Fire to refer to the four states of matter).

Gaiaphones, in which vibrations in solid matter propagate as vibrations in the surrounding air, are then further subdivided into the idiophones, membranophones, and chordophones (Fig. 1).

These classifications relate to how the instrument outputs (makes) sound, but if we go to a music store to purchase a musical instrument, we will find that the instruments are usually categorized by input (user-interface).

Classifying instruments based on their interface makes sense to a person who wants to buy an instrument, because, for example, someone who knows how to play piano, will also know how to play organ, to some degree. Thus he or she can try all the instruments in that section of the store.

Because of this recent shift in emphasis on user interfaces, we might want to expand the newly proposed physics-based classification of musical instruments along the input (user-interface) dimension as well as the output (sound-producing) dimension.

In view of the directness of user-interface that we are exploring in this paper, a logical choice of top-level user-interface categories would be the same categories newly set forth for the sound-producing classification, namely the state-of-matter of the user-interface.

We define a *direct user-interface* as requiring a position along the diagonal of this new classification system of Fig. 1. A pipe organ, for example, is not a direct-user-interface because the fingers are placed on solid matter (the keys of the organ) which (indirectly) controls the wind in the pipes.

A guitar can be a direct-user-interface because the fingers

Figure 2: This poseidophone is also a glass harp. Thus it can be played by rubbing wet fingers around the edges of the glasses, or by dipping the fingers right into the water. The glasses, with water, form very good aspheric lenses to concentrate the sun's rays (or rays from a stage light during a performance) onto high-temperature ceramic pickups that optically respond to sound waves (ripples) in the water. Alternatively, or additionally, a video camera and computer vision system picks up the sound.

are in direct physical contact with the very medium that creates the sound, namely the strings. Likewise a tin flute will fall along the diagonal in this classification system.

Moreover, the map of Fig. 1 suggests a possible new space of liquid-based instruments in which liquid is used instead of solid or gas, either for the sounding mechanisms, or the user interfaces, or both.

2.2 The poseidophone

The poseidophone, named after the Greek god of the sea, Poseidon[1], is made from an array of ripple tanks, each tuned for a particular note. The sound produced by the poseidophone is too weak for use in performances, and thus, out of necessity, it must be amplified somehow. This is usually done electrically, and thus there is generally one or more forms of electrical pickup associated with each ripple tank.

A note is sounded on the instrument by disturbing one of the ripple tanks, and chords are played by disturbing multiple ripple tanks simultaneously. Although a keyboard could be used to create these disturbances, it is preferable, in keeping with the spirit of remaining on the diagonal in Fig. 1, that the player disturb the ripple tanks by inserting fingers directly into the water.

A portable poseidophone is shown in Fig. 2. This particular poseidophone, permanently installed in a portable road case, is also a glass harp, so it can be played in a variety of different ways, i.e. by hitting or rubbing the glasses, i.e. playing it as an idiophone or friction idiophone. However, the preferable way of playing it is to dip the fingers into the water to make audible as well as subsonic sound waves. In this case it is no longer being played as an idiophone, but, rather, as something outside of any of the five top-level categories in the Hornbostel-Sachs taxonomy. The sound in the water waves extends beyond the range of human hearing, particularly at the bottom end, thus what we hear are mostly harmonics, sometimes assisted with additional processing. The audio from each pickup is often fed into a separate bandpass filter. Sometimes more than one filter is used for each pickup, in order to provide a fuller, more rich sound. Each pickup can be plugged into a separate guitar effects pedal, and with ten guitar pedals, the sound can be further shaped. For example, the sound can be modulated upwards, from the deep bass sound of the original poseido-

[1] The Greeks considered the sea-divinities to be primordial

Figure 3: The main architectural centerpiece in front of Ontario Science Centre is a fountain that is a hydraulophone, approximately 10 metres in diameter and 20 feet high. This one is reedless, but other hydraulophones include the Clarinessie (single reed), the H_2Oboe (double reed), and a wide variety of underwater orchestral instruments. (Leftmost 'glog by James Fung)

phone, to make it a lead or melody instrument [2].

One or more of the bandpass filters, modulators, up- converters, pitch up-shifters, etc., may be implemented by an oscillator in a way much like (but not exactly like) the way a superheterodyne radio receiver uses a local oscillator as part of a filter. Since some oscillators can be controlled by MIDI, the poseidophone is often used with MIDI, and thus, in addition to being an acoustic instrument, is also a MIDI controller. However, there remains an important physicality in the process of actually sculpting sound waves with the fingers, much as there remains a physicality in playing an electric guitar, whether the guitar pickup is magnetic or optical. Whether sculpting the sound waves on a guitar string, or the sound waves in a ripple tank, the important fact is that the fingers remain in direct physical contact with the sound-producing medium, namely the water.

2.3 The hydraulophone

Water is a very primordial element. It is often said that of all the modern inventions (television, radio, Internet, etc.), the invention that most captures the attention of indigenous persons when first brought into the modern world is the water faucet. Water is tangible, immediate, and easy to comprehend. The hydraulophone is an instrument that many children begin to play before they are one year old. Large hydraulophone installations (Fig. 3) are ideally suited to use in public parks because the array of water jets forms a self-cleaning keyboard instrument that can be shared with strangers without the usual risks of cross contamination that might occur if another instrument like a piano were left out in the middle of a park. There's no need to wash your hands when you're playing in a fountain!

2.4 Pneumatophone (florgan polyflute)

Pneumatophones are instruments that make sound pneumatically (i.e. with compressed air) in a way that is similar to the manner in which hydraulophones make sound hydraulically (i.e. with pressurized hydraulic fluid, typically water).

Two versions of the pneumatophone have been presented in previously published literature. See Fig. 1 and 2 of [2].

A previously unpublished version of the pneumatophone with acoustic pickups. has a number of 3/4" copper pipe tee fittings that each are supplied with wind (compressed air) at one end of the tee. The other end of the tee is the user-interface (finger hole). At the side-discharge port there is a thin membrane that pickups up air vibrations such as

[2]Poseidophones that naturally play in the higher registers tend to have small cups for the higher notes, and these cups often get too small to insert more than one finger into. Indeed, at some point, only the tip of the smallest finger will fit in the cup, and beyond that we loose the intimacy when we need to use a small actuator. Poseidophones can be built using nano-technology, but then they loose their human scale and their primal sense of immediacy.

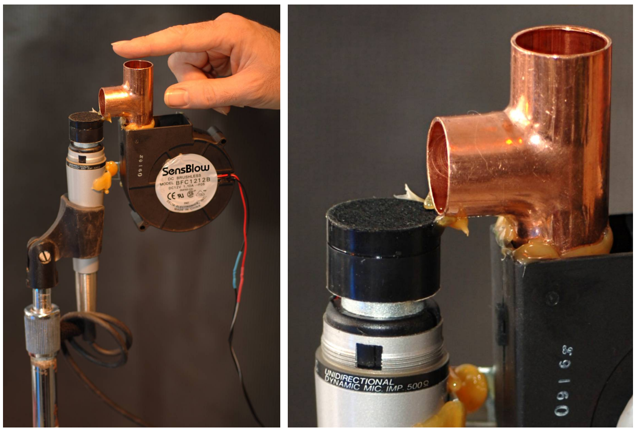

Figure 4: **One of the 12 pneumatophonic elements in a pneumatophone:** Placing a finger over the mouth causes air to blow against a thin membrane, causing the membrane to vibrate in various ways depending on the shape, position, orientation, and movement of one or more fingers at, in, or near the mouth of the instrument. In this instrument the membrane is simply that of a microphone with the mesh-ball windscreen unscrewed and removed (one microphone for each of the 12 notes in the instrument). A blower or air compressor supplies a steady stream of air at the bottom of each tee fitting (one tee fitting for each note).

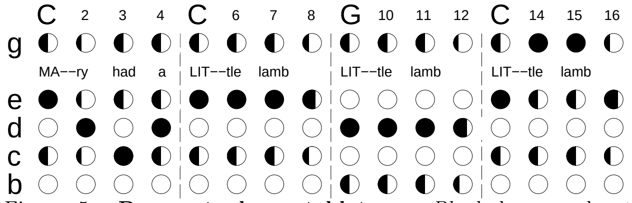

Figure 5: **Pneumatophone tablature:** *Black*ed areas denote *block*ed areas of the instrument's mouths. Capitals denote harmony, lowercase letters denote melody. For beat 1, a "C" chord is formed with emphasis on "e". During beat 2, where the melody is not a member of the chord, we ease off on the chord a little bit, by pulling the fingers back slightly, indicated as a lesser blacked-out (lesser blocked) region of the "g", "e", and "c" mouths. During beat 8, we ease off a little on the melody note "e" and the harmony notes "c" and "g", since there are no lyrics being sung during this beat.

eddy currents, turbulence, and other sounds made by the air. These sound vibrations may be picked up optically, magnetically, electrically, etc....

One of these instruments uses five tee fittings and five standard dynamic microphones in which the ball-shaped windscreen has been unscrewed and removed. Each microphone is attached to the side-discharge of each tee fitting as shown in Fig. 4. Each of the five microphones is plugged into a modified Cry Baby Wah Wah pedal. Each pedal is set differently by the musician. Usually the settings are updated only occasionally during a song, while most of the playing is done at the mouths of the instruments. Simple songs like Mary Had a Little Lamb can be played without touching the Wah Wah pedals at all, once they are set for a particular song. In this case the first pedal is set to shape the sound of microphone number 1 to approximate a "B" note. Pedal 2 (on microphone 2) is set to approximate a "C" note. Pedal 3 is D, pedal 4 is E, and pedal 5 is G.

Placing fingers near, into, onto, or around some of the instrument's mouths causes compressed air to hit, stir, flow, or eddy around the respective membranes in various ways.

Referring to the five mouths as "b", "c", "d", "e", and "g" (the notes that they principally play) we can write out a simple form of tablature for pneumatophone, as shown in Fig. 5. This tablature is similar to guitar tablature. Also, as with an electric guitar, an intricately intertwined harmony and melody can be played on nothing more than five tee fittings, five microphones, some compressed air, and some guitar effects pedals and amplifier. Unlike guitar, however, the pneumatophone can sustain notes for as long as desired. In fact there will always be a small amount of turbulence and eddy currents flowing past each pickup, so, technically speaking, every note on the pneumatophone is sounding to some degree all the time, and the player merely accentuates the degree to which notes sound, while also changing the way in which they sound. A noise gate is sometimes added to each pickup (by way of five other noise-gate guitar effects pedals) when this background drone is not wanted. However, usually some form of background drone is desired, so only some of the noise gates are shut off during only portions of a given song. Thus there are usually ten effects pedals for a 5-note instrument, and these are typically adjusted dynamically during the song, but only occasionally.

Staff-notation cannot express the intermix of overlapping (on the same compass) harmony and melody that is possible on a pneumatophone. We refer to this intertwined and overlapping harmony and melody as "harmelody". Pneumatophone tablature can be extended to produce what we call "fluid music notation" ("harmelodic notation") which resembles a multicolored Time-Frequency Distribution (TFD), wavelet transform, or spectrogram.

2.5 The acetophone

The acetophone is a horizontally mounted pipe with 12 air holes running along its length. It is powered by acetylene, supplied by a hookup to an acetylene tank. Initially, there are 12 flames burning, but if the player covers up one of the air holes, the corresponding flame will be deprived of oxygen supply, and the flame will make a loud bang as it is extinguished. Anybody who has used an acetylene torch will no doubt be familiar with this loud bang whenever the air supply is shut off.

The acetophone is an aerophone, since the sound is produced by gas (acetylene, oxygen, and combustion gases).

Although an acetophone can be played using a keyboard to control air valves, it is preferable, in keeping with the spirit of remaining on the diagonal in Fig. 1, that the player interact with the acetyphone by having his or her fingers in direct contact with the air.

All 12 flames and finger hole systems are identical and sound identical. What makes the acetyphone melodic is a set of resonators through which the sound vibrations from the flames pass. In small chamber performances acoustic resonator pipes are used. In larger performances, 12 microphones are used, one for each flame. The output of each of these 12 microphones is run through a bandpass filter, to select out the frequency of the desired note from the broadband snapping sound of the flame extinguishing.

Regardless of whether the bandpass filter is acoustic, analog, digital, or implemented by oscillators (sometimes MIDI controlled oscillators), the instrument is still an aerophone, and not an electrophone, because the initial sound vibrations come from air, not electricity. The electricity (whether MIDI, digital, analog, or the like) serves merely a post-processing role, after the initial production of the sound has been made by the demise of one or more flames.

Chords can be played by blocking multiple air holes at the same time.

An electric starter re-ignite any of the flames when the corresponding air hole is no longer blocked.

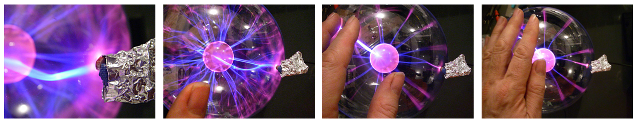

Figure 6: **Plasmaphone:** Sound is produced by plasma. A number of different kinds of plasmaphones have been built by the author, with various kinds of pickups. The one shown here uses optical pickups (wrapped in foil for shielding from high voltage interference) on each of several plasma balls. As more fingers come closer to one of the plasma balls, plasma is drawn away from a pickup, resulting in dramatic changes in the sound produced.

The acetophone has a MIDI output, making it easy to use it as a controller for a
pyrophone [http://en.wikipedia.org/wiki/Pyrophone] Modern pyrophones (consider Satan's Calliope, for example) generally have MIDI inputs.

See also, http://www.vu.union.edu/ stodolan/pyrophone/ (thermoacoustic organ).

2.6 "Rectifire"

It is well known that one can quickly run one's fingers through the flame of a Bunsen burner, candle, or torch flame without pain or damage.

The rectifire makes use of this fact by way of a linear array of flames through which the player runs his or her fingers to play the instrument. The instrument can be played with or without asbestos gloves, but playing without gloves provides some interesting physical constraints and physicality to the music that stays more within the "pysiphone" spirit.

Acoustic, optical, or electric pickups are fitted to each flame to pickup changes in the sound of the flame due to insertion of the finger.

A different variation on this fire and water theme has been previously reported[2],p190.

2.7 TESLA-KEYS

The Transcutaneous[3] Electrical Sounding Linear Array for Keyboard-like Electrically Yielded Sound (T.E.S.L.A. K.E.Y.S.) is a musical instrument invented by author S. Mann in the 1970s, consisting of an array of spark gaps into which the player inserts his or her fingers to produce sound. Sound is produced by sparks occurring in direct physical contact with the fingers of the player.

One embodiment was made using eight 6-volt automobile ignition coils originally used in Model-T fords. Current limiting resistors were used to keep the stimulation levels below the pain+damage threshold. Each spark gap is adjusted so that it does not quite arc, until a finger is inserted. Each Model-T ford coil has an integral electrotome that can be adjusted for tuning over the desired range of notes, the sound being made directly by sparks at the desired pitch. The result is an acoustic instrument that can be used in small chamber settings, or can be used as a source of excitation for an array of Tesla coils, thus becoming a user-interface to an ionophone or Tesla organ. In either case, the fingers of the musician are in direct physical contact with at least the first stage of sound-producing sparks.

2.8 The plasmaphone

The plasmaphone is similar to TESLA-KEYS but the plasma is contained in an array of glass balls that the player touches (Fig. 6). Since the plasma effects occur at high frequency, the plasma may still, in some sense, be regarded as

[3]Transcutaneous means applied through the unbroken skin, i.e. unlike some versions of the instrument that use implanted electrodes.

Figure 7: **Another variation of the plasmaphone at the 2006 PineHill Christmas Concert, December 25th:** Commercially made high voltage plasma mugs bought from a novelty store are designed to be filled with water and touched. The author bought nine of these "plasmugs" and made them into a highly expressive "plasmacoustic" instrument.

being in contact with the player's fingers despite the glass barrier.

2.9 Poseidoplasmaphone

The poseidoplasmaphone (Fig. 7) combines water and plasma.

2.10 The xenophone

The xenophone consists of 12 xenon flash tubes (from camera flashes) each flashing into a separate resonant pipe. The flash tubes are excited to just slightly less than what is required to fire them. The instrument is played by stroking the flash tubes with the fingers, to get them to fire. For reasons of user comfort and safety, a small flash tube making a small sound is used either to activate a much larger (and louder) flash tube such as GE Mazda FT623 (40,000 watt-seconds) or the weak sound of the smaller flash tubes is amplified by way of acoustic, electric, or optical pickups.

2.11 The Gaiaphone

The Gaiaphone, named after the Greek goddess of the earth, is an instrument that is played by stomping on it. A phased array of geophones, sometimes mounted in giant resonant pipes, beneath the earth, pickup up the sounds and feed them to a computer. The computer analyzes the sound using Morlet wavelet theory, and modulates it up into the audible range of human hearing, but includes also the subsonic parts of it.

The Gaiaphone can be played like a foot piano (regions of the earth are organized by frequency) or like an andantephone (regions of the earth are organized by time). In the first case, sounds from the geophones are used to compute direction and location information for a seismic disturbance in each of 12 different regions, at the same time. Disturbances in a first region, say, region-A result in the sounding of an "A" note by passing the actual seismic activity through bandpass filters and other effects processors. Disturbances in a second region are filtered to sound a whole tone higher ("B"), and so-on, to make a musical scale that one or more players can play with their feet. An alternate version of the instrument is played in a pool, in which hydrophones are used instead of seismophones.

2.12 Idioscope and Glockenspark

Any of the new instruments in this paper can be assisted by computer vision. One example comes from an electric xylophone made of 88 blocks of wood, each with its own microphone connected to a separate bandpass filter. Each bandpass filter is tuned to a separate note, like the notes on a piano. The blocks can be identical, or they can be sized to each resonate at the desired frequency so that some of the bandpass effect comes from the wooden blocks themselves.

An improvement to the author's electric xylophone was made by using only two microphones, one in each of the two sticks and simply using an overhead camera to see which block was being hit. A computer then selected and implemented an appropriate bandpass filter for each block hit. Moreover, any desktop surface with data projecter can become the instrument, using the real sound of a real stick hitting real wood to make the sound, then filter it with the computer, choosing a center filter frequency based on where on the desk a stick hits. (A stereo sound card in the computer does 2 separate bandpass filter channels, with one stick held in each hand). Microphones can also be fitted to the hands or the desk itself for direct (stickless) hitting.

This **idioscope** (camera-assisted idiophone) evolved into the glockenspark, in which 88 metal bars, connected to high voltage (at a safe and very low current) are touched by the user. Sparks fly to the fingertips (or to insulated metal sticks for people afraid of direct touch), and computer vision determines which bars are touched. The audio output from the computer then goes back to one or two high voltage supplies, so that the sound is actually produced by sparks. The result is an entirely acoustic instrument in which plasma is both the user-interface as well as the sound-producing medium.

2.13 Quintephones

It is proposed that instruments in the fifth state of matter be generalized beyond electrophones to include **optiphones** for sound production by non-electric informatics, optical computing, or any other newly invented means.

3. DISCUSSION AND CONCLUSION

A large range of newly invented musical instruments have been presented. Each of these inventions has a simplicity of user-interface like a keyboard instrument, but none of them is merely a user-interface. When physiphones are used as MIDI control surfaces they are acting as hyperacoustic hyper-instruments, not merely as user-interfaces, since each of these newly invented instruments has a linear array of real physical processes, each with a resonator (much like the Hsain Wain, a large circle of graduated drums that looks like a pipe organ but is a membranophone). This physicality serves as both a user-interface and a sound-production medium. Many of these newly invented instruments do not fall within any of the five Hornbostel Sachs categories. None of them are merely electrophones or merely interfaces to electrophones. In all cases, the initial sound production (the first vibrating element that makes sound) is due to a real physical process. These new instruments may be called "physiphones" from the Greek words "physika", "physikos" (nature) and "phone" (sound).

Inventing these new instruments has shown the limitations of previously known musical instrument classification systems. A new classification scheme was proposed, the top-level of which is the initial sounding mechanism's state of matter: Earth, Water, Air, Fire, or Quintessence!

4. REFERENCES

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