WATER JETS AS PIXELS: WATER FOUNTAINS AS BOTH SENSORS AND DISPLAYS

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ABSTRACT

We propose a hydraulic user interface consisting of an array of spray jets and the appropriate fluid sensing and fluid flow control systems for each jet, so that the device functions as a fluid-based tactile user interface. Our array of fluid streams work like the keys on a keyboard, but where each fluid stream can also provide tactile feedback by dynamically modulating the pressure of the fluid spray, so that the keyboard is actually bi-directional (i.e. is both an input and an output device).

A 104-jet version can be used as a fun and tactile "QWERTY..." style keyboard. More importantly, however, the device can also be used for applications, such as musical instruments, where its more expressive multi-dimensional input capabilities can be put to full use.

One such instrument, the hydraulophone (hydrauliphone, hydraulaphone), is a hollow tubular object with a row of holes in it. It is played much like one would play a tin flute or recorder, by covering up the holes to restrict fluid flow.

This gives rise to a fun new way of playing music by successively blocking water jets in a fountain, or while frolicking in a pool, or splash pad. Additionally, the hydraulophone can be used as a teaching tool to help children learn music by playing in the water. We demonstrate this teaching capability by way of an implementation of the arcade game "Touch Me" using a hydraulic user interface.

We describe some of our present and upcoming installations of these devices in public parks, pools, and aquatic play areas.

0.1. The hydraulophone

In this paper we explore the use of fluid-under-pressure (e.g. pressurized water) for both the production of sound, as well as for use as a direct (and tangible) user-interface. This research derives its inspiration from the screeching sounds made by defective faucets, and other valves with liquids passing through them, giving rise to the discovery and exploration of various water-based multimedia devices such as musical instruments [1]. In particular, various underwater musical instruments were made from simple devices (some hand-cranked or pumped like an accordion, others motorized) that rapidly turned water jets on and off, or forced water through resonant orifices, and, additionally, other water-based musical instruments and interfaces such as organ pipes with water actually flowing through the pipe and fipple mechanism, were explored [1]. These new interfaces were a big hit with children at public pools. Additionally, we use some versions of the hydraulophone as an electronic input device for various multimedia applications. [1].

In the electronic versions of our instrument, we attempted to maintain the same soulful melancholy sound of our original acoustic hydraulophone, which results from its unique ability to independently and continuously modulate individual note amplitudes, pitches, vibrato, and timbre. The mournful cry of the instrument, like the sound of a haunting call of a loon in the wilderness, was something that users have really connected with, over the course of demonstrations in public.

Tangible media [2][3] have been demonstrated in various forms. Our arrays of water jets as a new multimedia interactive design element, could be considered an example of tangible media.

0.2. Water jets as interactive media

In addition to the sound that emerges from the instrument, there is also other feedback to the user. For example, the tactile feedback of the water jets is an important design element that can also be modulated interactively so that the jets can be made to feel differently on the flesh, by way of computer modulation, in response to changes in internal state of the system.

Additionally hydraulophones often feature a certain number of "system status jets" that function as a display, much like Koert van Mensvoort's datafountain (a fountain that is used as a display device to show stock values as height of water column). Others have also used fountains as displays (e.g. the fountains in front of the Bellagio hotel, designed by Mark Fuller of WET Designs, function as a display and "dance" in time with music).

Our work combines fountain data display with the ability to use the water jet as an input device. To do this, the system senses the manner in which the jet is being obstructed (by way of back pressure, flow rate, restrictometry [1], etc.).

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Fig. 1: **Aquatic "Simon" game:** Computer-controlled educational version of a hydraulophone, in which the user interacts with water jets. "Simon" demonstrates how a musical melody is played, by adjusting water flow through the jets. Users who can repeat the melody by covering or diverting the correct water jets are rewarded, and move on to the next level of difficulty. If a user makes a mistake, a buzzer sounds.

1. ARRAYS OF WATER JETS AS HAPTIC SURFACES

We have designed and built various multimedia applications, as devices based on water jets. These devices are user interfaces with different combinations of tactile, visual, and acoustic interaction with users.

In other work we have reported on using optical means to measure water column height very accurately [4] and thus, with enough jets, a two dimensional or three dimensional haptic surface results.

1.1. Hydraulophone: Fluid jets as a musical keyboard

The fluid user-interface is also well suited as new musical instrument. Properties that make fluid jet user-interfaces well suited as a musical instrument are its large dynamic range of user input, as well as its ability to continuously and fluidly update the output signal using one's finger.

We have designed and built a number of fluid-based musical instruments, which we call hydraulophones. Many are human-powered and entirely acoustic, while others are hybrid electronic-acoustic. Still others are purely electronic (i.e. the array of water jets is merely a haptic surface which is used as a control surface for general-purpose multimedia input).

Examples of purely acoustic hydraulophones, which embody the hydraulophone concept in its purest form, include a user-interface that comprises an array of water jets that each function like a key on a keyboard instrument.

Hydraulophones, whether in their purely acoustic embodiments, or their electronic embodiments, or hybrids, are usually played by touching, diverting, restricting, or obstructing in various ways the water jets in the array. Often the jets are arranged in a row, like the keys on an organ or piano. The more one's finger blocks a jet, the more fluid that is diverted to the sounding mechanism, resulting in increases in sound volume. Moreover, by placing or approaching one's finger from above or beside the water jet, the user can affect the sound in a variety of different ways. For example, on some acoustic hydraulophones, the sound can be made louder and brighter in timbre, as well as manipulated in various other ways (pitch bend, vibrato, etc.), based on slight changes in the way that the finger rests upon the fluid jet. This wide range of interactional possibilities of the hydraulophone allows a musician to attain a high degree of expressional variation in the sound. In this way the hydraulophone is very much like a flute (and many other wind instruments), where a musician can exert embouchure control using his/her mouth on the instrument's mouthpiece. However, unlike the flute, the hydraulophone leaves one's mouth free to sing along while playing it.

Many woodwind instruments have a row of holes arranged in a somewhat diatonic or linear pattern, and to achieve each note, there is a particular somewhat complicated fingering pattern that must be remembered. Since the holes are used in various combinations of this sort, these instruments are purely monophonic.

The hydraulophone, however, associates one hole to each note. Therefore, for playing melodies (monophonically, one note at a time), the hydraulophone is much easier for children to learn.

Another side-effect of the fact that each jet, together with its sounding mechanism, corresponds to only one note, is that the instrument is able to polyphonically (e.g. to play chords), unlike wind instruments such as flutes, clarinets, saxophones, and the like.

The hydraulophone's richness as a user-interface exists both through rich, continuous expression which is possible on individual water jets, and through the ability to combine and interleave the playing of several jets as interleaving musical chords. As a user manipulates the water jets, the hydraulophone user interface provides tactile feedback, visual feedback (appearance of the jet streams downstream from where they are touched), and auditory feedback.

The auditory feedback comes as amplitude, timbre and pitch for each note, and quantized steps of pitch for the sequence of different jets.

2. PRESSURIZED WATER AS A NEW HYDRAULIC USER-INTERFACE

We have expanded the ways in which a user interacts with a hydraulophone, by adding solenoid-operated valves which control the flow of water coming out of each jet.

With this addition, the hydraulophone can act similarly to a player piano, by having jets shoot up and stop in a pattern, so that the device can play a song by itself, creating also the

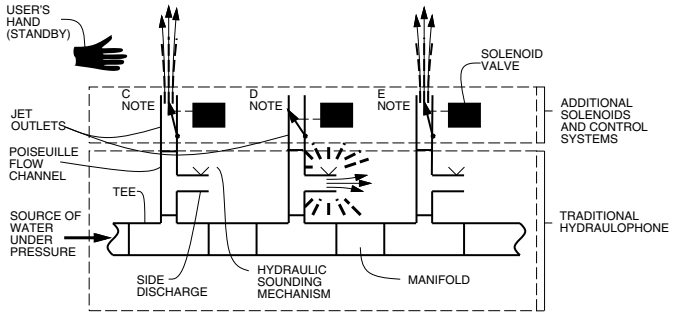

Fig. 2: **Solenoid valves added to a traditional hydraulophone to make it into a player-hydraulophone:** The hydraulophone works like a "player-piano" and plays a portion of a song. Here it is shown playing one note (D). It does this by closing the valve associated with the D note, which diverts water to the hydraulic sounding mechanism. To the user, it appears as if a hidden player is blocking that one jet to make it sound.

same visual pattern of jets going on and off, as if a human participant was interacting with it.

The solenoid-operated valves are additions that can be fitted onto any hydraulophone, whether acoustic, electronic, hybrid, etc., and if the valves are disabled, the hydraulophone returns to its generalized form as a richly expressive musical instrument. (We achieve this default behaviour by using naturally open valves, so that when the wires to the solenoid valves are unplugged, the instrument works just like an ordinary hydraulophone.) Fig. 2 illustrates how our hydraulic actuation is added to our hydraulophone interface. The hydraulic actuation expands the bidirectionality of user interaction, augmenting the acoustic feedback, tactile feedback, and visual feedback from the hydraulophone.

We set out to explore new creative uses of this new capability to control the hydraulophone's water jets. The result was a series of musical teaching tools, games, etc.. In particular, we were inspired by the computerized children's game, Simon, where a computer plays musical tones, and the user tries to play the same tones over again without making a mistake. The Simon game helps develop musical memory skills, and the game becomes more and more challenging as the user progresses to higher and higher levels.

2.1. Fluid jets with the Simon game

In the hydraulophone implementation of the Simon game, we set out to create a multimedia station that serves to teach the user something new, in the form of a song. While the original Simon game played only random sequences of tones, the game we present requires the user to play back common songs in an effort to teach the melodies for future performances. The fact that familiar melodies, rather than just random sequences of tones, are being played, lend our variation of the Simon game to being built onto existing public hydraulophone installations, as an educational tool toward teaching hydraulophone technique, and music in general. Moreover, unlike the original Simon game which only had four binary on/off buttons, our game has 12 continuous almost-analog (highly expressive 16-bit precision) inputs.

See our video supporting material in http://wearcam.org/simon/index.htm

Figs. 1, 3, 4 illustrate a number of public field trials of our hydraulophone Simon game.

Our version of Simon, as a teaching tool, has various degrees of difficulty. In early stages of the game, all that is required of the user is the pressing of a water beyond some preset threshold. More advanced stages of the game will test the user's ability to more accurately control the water columns that make up the hydraulophone's dynamic input.

By controlling the water jets in the hyraulophone's Simon game, the instrument provides not only visual feedback, but also tactile feedback. A blind person would be able to place their hands over the water jets as the pattern is played, and feel which notes are being turned off and in which order. The soothing nature of the liquid interface has been shown to be well-suited for music therapy in old-aged homes during field trials that were conducted.

Additionally, we are currently using the hydraulophone to combine water therapy and music therapy for special needs children.

3. GAME-PLAY

The objective of the game is to use the hydraulophone to play back a melody stored in the game's memory.

The game sequence is as follows:

- The game initially plays a portion of a song (often just the first note of the song) and then waits for user input;
- If an incorrect note is played by the user, the water jets shut off and a dissonant sound is produced to discourage the user from making mistakes;
- If the portion of the melody is played back correctly, right from the beginning, then the user is informed so by the playing of an encouraging check-mark sound, and the game advances to the next note. At each such stage of correct input, the game adds one more note to the notes that the solenoids play on the hydraulophone.
- Upon completing the entire melody, the user is rewarded by a special celebratory dance of water and music.

Since the user both hears,sees, and feels the water-jets being turned off and on, the melody is reinforced in multiple ways. The user then attempts to play back the melody.

4. ADVANCED ISSUES IN GAME-PLAY

A critical issue addressed in the design of the game is determining when a user's input can be considered a deliberate note input. An underlying principle behind the hydraulophone's design is that all of the water-jet notes are always on: notes are not turned off and on but rather the volume of

Fig. 3: A user playing one note, trying to copy what Simon "said".

each note is updated based on user interactions with the corresponding water jet. A degree of uncertainty then inevitably arises, as to how much of the water jet needs to be blocked to be considered a note-on, in the version the game that is binary (before the game advances to expecting the player to partially obstruct a water jet to the correct degree). Through iterative field testing, an input threshold level for each of the water-jet notes was set at a level that produced a sound that could reasonably be heard in a public space. The note is not considered OFF however, until the note passes through a much lower off-threshold. This provision was taken to ensure that the game was user-friendly in that a note could not bounce on and off, being registered more than once around the threshold point.

The result of using threshold levels in early stages of the game is that user will be able to learn the notes to a particular melody, but still have a significant degree of freedom (beyond the threshold) with which the notes can be played. Future work includes further limiting what is considered a correct note, in that the User must more accurately reproduce the exact volume and dynamics of the notes to be played. Harmony (e.g. chords) and correct tempo during playback are required only in more advanced levels of the game.

5. CONCLUSIONS AND SUMMARY

We have presented examples of a fun haptic surface that takes the form of a hydraulophone that works like a player piano. The instrument uses water as both an input and an output device. As an output device it is related to the datafountain (or the fountains in front of the Bellagio hotel, etc.), but also as an input device, it adds a new aspect to multimedia art, namely that of immersive multimedia. This new immersive quality follows from the fact that (1) it uses fountain jets as input/output rather than just output/display (2) it involves direct tactile interaction (immersive multimedia) with the water as the interactive medium.

Fig. 4: As a public multimedia interface, the "Simon" hydraulophone has been demonstrated and tested at various public places.

In designing a new and useful system for teaching children music, we demonstrated how playing in the water could be an engaging and educational experience when combined with simple arcade games like Atari's "Touch Me".

6. REFERENCES

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