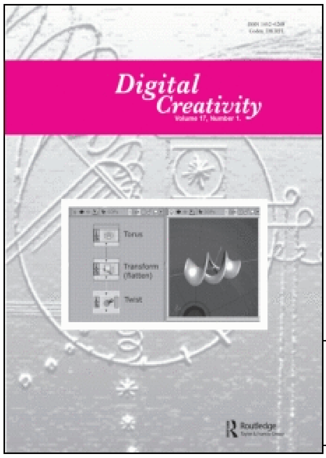

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Augmenting sonic reality. Cyberinstruments designed with digital waveguides

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Abstract

This article discusses how cyberinstruments created with digital waveguides—a technique for physical modelling synthesis, enable the augmentation of musical reality. These facilitate efficient replication of musical instruments and allow the extension of the properties of the replicas beyond the limitations of the physical world. The article examines how different composers have manipulated cyberinstruments designed with waveguide synthesis to stretch the sonic identities of physical instruments.

Keywords: cyberinstruments, physical models, digital waveguides, interactive music composition, augmented sonic reality

1 An introduction to digital waveguides

Digital waveguides is one of the physical modelling sound synthesis techniques. Physical modelling enables computer simulations of sonic structures based on the understanding and implementation of their underlying mechanics, including musical instruments, environmental phenomena and everyday objects. Physical modelling synthesis is an excellent vehicle for conceptualising the reality of these sounding classes (Borin et al. 1992; Smith 1992).

What differentiates this technique from other synthesis techniques is the fact that physical modelling simulates sound production mechanisms, while other techniques (e.g. additive, subtractive and frequency modulation synthesis) simulate the way a signal reaches the human ears. For instance, where the spectral modelling approach represents the different combinations of frequencies and amplitudes resulting from a bow-string interaction, the physical modelling approach can be used to simulate the actual *mechanics* of that interaction.

The digital waveguides are a specific physical modelling sub-synthesis which emerged from a combination of the Karplus-Strong digital synthesis algorithm (Karplus and Strong 1983) and the McIntyre, Schumacher and Woodhouse numerical simulation approach (McIntyre, Schumacher and Woodhouse 1983). Julius Orion Smith and David Jaffe extended the Karplus-Strong algorithm in 1983 (Jaffe and Smith 1983), and Smith subsequently pioneered digital waveguide synthesis (Smith 1992), developing

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several efficient simulations of different instrumental classes[1]. In the years that followed digital waveguide synthesis became a common method for modelling most musical sources, with researchers like Davide Rocchesso, Perry Cook, Vesa Valimaki, Georg Essl, Stefania Serafin, Stefan Bilbao expanding on Smith's research and proposed models of numerous sounding objects.

A basic waveguide model consists of an exciter and a resonator as shown in Figure 1. The exciter is the source of energy applied to the instrument, like a bow interacting with a string and the air flowing inside a flute. The resonator is the object which has been excited, such as a string coupled with the body of an instrument or the tube of a flute.

A digital waveguide is a medium in which a wave propagates (Smith 2004). Digital waveguides can be used to represent waves propagating along one-dimensional structures such as strings or tubes, but also multi-dimensional structures such as singing bowls and plates. Musical instruments and sounding objects can be simulated by pairing a digital waveguide, that is, a resonating structure in one or multiple dimensions, with an appropriate excitation mechanism. Additionally, digital waveguide synthesis allows the free combination of exciters and resonators and thus the generation of hybrid models. (For example, a 'blown string' model may result from coupling a blowing excitation with a string resonator.)

When accurately implemented the control parameters of waveguide models correspond in number and nature to the control parameters of a physical instrument. This allows a musician to approach virtual models as intuitively as they would a physical instrument. Implementation of the waveguides in real-time applications such as Synthesis ToolKit (Cook and Scavone 1999), MAX/MSP (Puckette 2002; Zicarelli 1998) and Pure Data (Puckette 1996) has stimulated a wider use of these physical models in music.

2 Cyberinstruments created with physical models

Cyberinstruments, the virtual sounding structures used in musical composition, can be most efficiently designed via physical modelling synthesis. There are three categories of cyberinstruments: extended, hybrid and abstract. The extended instruments are simulations of existing instruments with the ability to augment the instrument's parameters beyond the limitations of their physical origin. A cyberstring, for instance, allows for the augmentation of its length, thickness and material beyond the limitations of the physical world. Jaffe used a string as long as San Francisco Golden Gate Bridge in his infamous composition *Silicon Valley Breakdown*. Hybrid instruments are typically an amalgamation of the properties of two or more existing instruments such as an *ublotar* (Stiefel et al. 2004) and a *blotar* (Trueman and DuBois 2005), which combine the properties of flute and guitar. Abstract instruments are those inspired

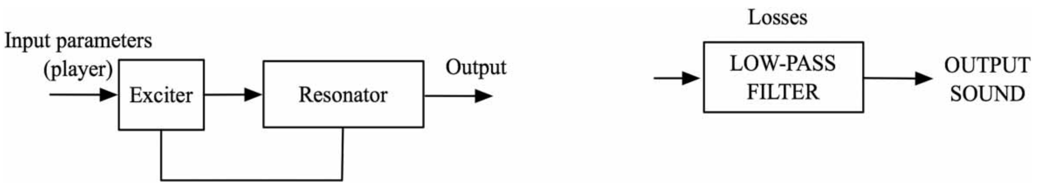

Figure 1. The exciter-resonator approach in waveguide synthesis. The exciter, i.e., the source of energy, represents the input to the resonator, e.g. the body of the instrument. A low-pass filter may account for the simulation of the losses.

by physical laws, but with no equivalents in the physical world such as Cadoz' triangular network of masses and springs in his *pico..-TERA* (Cadoz 2002). The detailed topology of cyberinstruments created by means of physical modelling synthesis is described in Kojs et al. (2007).

As a general rule any physical modelling technique can be used to model any cyberinstrumental type. However, practice has shown that some techniques are more suitable than others for the simulation of particular instruments due to their design nature and mathematical effectiveness. While extended instruments are frequently modelled with waveguide synthesis, modal synthesis is effective in simulating of cyberhybrids. The mass-spring-damper algorithm facilitates the design of abstract cyberinstruments. The following section briefly reviews different compositions written with extended cyberinstruments known to the authors.

Matthew Burtner used cyberstrings and cyberbowls designed by one of the authors in his compositions *S-Trance-S* (2001), *S-Morphe-S* (2002) and *That Which Is Bodiless Is Reflected in Bodies* (2004) (Serafin et al. 2002; Serafin 2004). In *S-Trance-S*, a piece for augmented saxophone and electronics, the composer distorted the identity of a bowed cyberstring and mixed it with the sounds of an acoustic saxophone. While parametrically stretched, the cyberstring dissolves to coloured noise in the course of the composition.

That Which Is Bodiless Is Reflected in Bodies investigates beating frequencies—the characteristic Tibetan bowl sonic feature. The cyberbowl enabled the composer to generate beatings in a multitude of spectral variations and rhythms, the continuous striking of the instrument producing a myriad of expressive transients. The composer augmented the bowl's sonic space with spectral detuning and registral expansion.

Chris Chafe extended the sonorities of cyberbrass instruments simulated with waveguides by Cook (Cook 1992) in an improvisation-based composition named *El Zorro* (1991) and effectively used the same technique in his real-time installations *Oxygen Flute* and *Ping. Oxygen Flute* is an interactive real-time computer music environment designed by Greg Niemeyer and Chris Chafe (Chafe 2005) in which a visitor enters a greenhouse space and excites a set of cyber-flutes with breathing. Chafe modelled four 9000-year old Jiahu bamboo flutes with digital waveguides which delicately expand and contract in *Oxygen Flute. Ping*, also created by Chafe, is a network environment, which involves a series of parametrically expanding and contracting plucked cyberstrings.

Juan Reyes engaged various cyberinstruments designed with digital waveguides in *Straw-berri* (1997, cyberflute and plucked cyberstrings), *Freddie the Friedlander* (2004, bowed cyberstring), *Wadi Musa* (2001, cyber-clarinet) and *ppP* (2001, cyberpiano). In *ppP* for piano and electronics, his cyberpiano expanded the sonic range of the physical piano. The cyberpiano strings are elongated and shortened, struck and plucked, loosened and tightened. The simulated musical effects include extreme pitch fluctuations, detuning and retuning of the strings, generating, expanding the instrument's registers, and modifying the natural envelope of the struck-string gestures. The extensions gradually strengthen the relationship between the physical and cyberinstruments.

Other examples of works in which extended cyberinstruments designed via digital wave-guides functioned to augment the sonic possibilities of a musical instrument include Achim Bornhoeft's *Virtual String* (1997, plucked cyberstring), Paul Lansky's *Things She Carried* (1997, plucked electric cyberguitar) and *Still Time* (1993—94, slide cyberflute), Bernd Lintermann and Torsten Belschner's interactive 3-D installation *SonoMorphis* (1998, 2007, cyberpipes and cyberstrings) and Coffey's works which engage glass cyberharmonica such as *Armonica Lullabies* (2004), *Koans* (2004), *Armonica Lullabies 2* (2005), *Never Ate So Many Stars* (2006), *No Further Meaning* (2007) and *Lullabies & Protest Songs: Suite No. 1* (2007).

The researchers rarely design cyberhybrids which fuse parts of multiple instruments in one model with digital waveguides. Nevertheless, Dan Trueman programmed the *blotar* that combines properties of the waveguide flute model with Charles Sullivan's electric guitar model (Sullivan 1990). Alternating the strength of the cyberflute and cyberguitar parents in the synthesis creates new timbres, depending upon the prevalence of these instruments' parameters in the synthesis. Gary Scavone designed and compositionally implemented two blown cyberstrings in his *Air Study I* (2002) for alto saxophone and electronics. Exerted pressure on the saxophone's reed and varied blowing inside the instrument excite and control a pair of cyberstrings.

3 Extended cyberinstruments in Kojs'compositions

Kojs compositionally explored a multiplicity of extended cyberinstruments designed with digital waveguides as shown in Table 1. The physical and virtual traditional instruments, ethno instruments and everyday objects simulated with this method are combined to create augmented sonic realities in a variety of compositions detailed in the table below.

The following sections describe individual compositions. While some pieces are discussed at length, those detailed in other published articles are covered more briefly. In both cases, the focus is on summarising the design of particular waveguides and the types of extensions they facilitate.

3.1 Singing cybertubes in *Garden of the Dragon* (2003)

Garden of the Dragon, for amplified cellophane, plastic corrugated tubes and electronics explores the musical possibilities of a daily object (cellophane) and musical toy (plastic corrugated tube). The sonorities of plastic corrugated tubes are paired with the timbres of the cybertubes which was simulated using one-dimensional waveguide. Bursts of cellophane and sonic input of the physical tubes excite the virtual tubes that are augmented to dimensions unattainable in the physical world. The singing tube model and the composition are detailed in Serafin and Kojs (2005).

3.2 Bowed and plucked cyberstrings in *Three Movements* (2004)

Three Movements is a composition for unprepared piano and electronics. The acoustic piano excites the virtual strings while highlighting the acoustics of its own sound production. The cyberstring used in *Three Movements* is a combination of three digital waveguides connected in parallel. It is excited by a friction mechanism, specifically the friction interaction as described in Serafin (2004), implemented in MAX/MSP as an external object called *squeaking* ~ with the following inputs: frequency elements, bow force, bow velocity, bow position and residual component. Figure 2 displays the MAX/MSP implementation of the bowed string.

The cyberstring generates a supplemental timbre layer in *Palms on the Strings*, the first of *Three Movements*. This movement employs a number of pre-recorded and pre-processed friction cyberstrings. The strings generate a background tapestry for evolving sonorities of the piano performed inside.

The performer slides their nails, knuckles and palms on top of the keys without fully depressing them in *Sliding Quietly* (the second movement). Since the hammer never strikes the string, no pitch is produced. Instead it generates an array of slightly pitched percussive sonorities. These sonically original nuances form the expressive range of the instrument, with the resonant frequency of the sound proportional to the velocity of performed glissando gesture.

Title	Year composed	Instrumentation	Cyberinstrument	Physical modelling approach	Implemented environment and designer
Garden of the Dragon	2003	Amplified cellophane, plastic corrugated tubes and electronics	Singing cybertube	1-d waveguide	MAX/MSP; S. Serafin
Three Movements	2004	Unprepared piano and electronics	Bowed cyberstring	1-d waveguide	MAX/MSP; S. Serafin
Revelations	2005	Circular toys, resonant plates and electronics	Bowed percussion cyberbar	1-d banded waveguide	MAX/MSP-PeRColate; Georg Essl and Perry Cook; D. Trueman and L. Dubois impl.
			Bowed cyberstring	1-d waveguide friction model	MAX/MSP; S. Serafin
Air	2006	Fujara and electronics	Cyberfujara	1-d waveguide	MAX/MSP; S. Serafin
To Where He Waited	2006	Cello and electronics	Cybermembrane	2-d waveguide mesh	MAX/MSP- PeRColate; Julius Smith and Gary Scavone; D. Trueman impl.
Concealed	2006	Flute and electronics	Cyberflute	1-d waveguide	MAX/MSP- PeRColate; Model by P. Cook; D. Trueman and L. Dubois impl.
In Secret	2006	Oboe and electronics	Singing cyberbowl	1-d banded waveguide	MAX/MSP; S. Serafin
En Una Noche Oscura	2007	Flute, violin, cello, piano and electronics	Singing cyberbowl	1-d banded waveguide	MAX/MSP; S. Serafin
Neither Stirred, Nor Shaken	2007	Cocktail glasses, shakers, blenders and electronics	Bowed cocktail cyberglass	1-d banded waveguide	MAX/MSP; S. Serafin

Table 1. Kojs' compositions written with extended cyberinstruments.

Hand-sliding actions also function as an excitation mechanism for virtual bowing. Two microphones positioned over each end of the keyboard sonorities transmit the signal to MAX/MSP, where it is amplified and fed to excite the bowed cyberstring. This results in the simulation of either *saltando* or plucked string sonorities. The frequency spectrum of the cyberstring is pre-assigned and corresponds to the overall pitch design of the composition.

For the most part the pianist performs in normal mode without depressing the keys in *Bowed Fingertips*, the third movement, with the cyberinstrument functioning as a resonant space for the keyboard performance. In its opening section the pianist's percussive impulses excite the cyberstring in the same way as in the second movement. Later in the movement, however, the pianist depresses keys fully and produces pitches. These are analysed in MAX/MSP and provide the real-time input

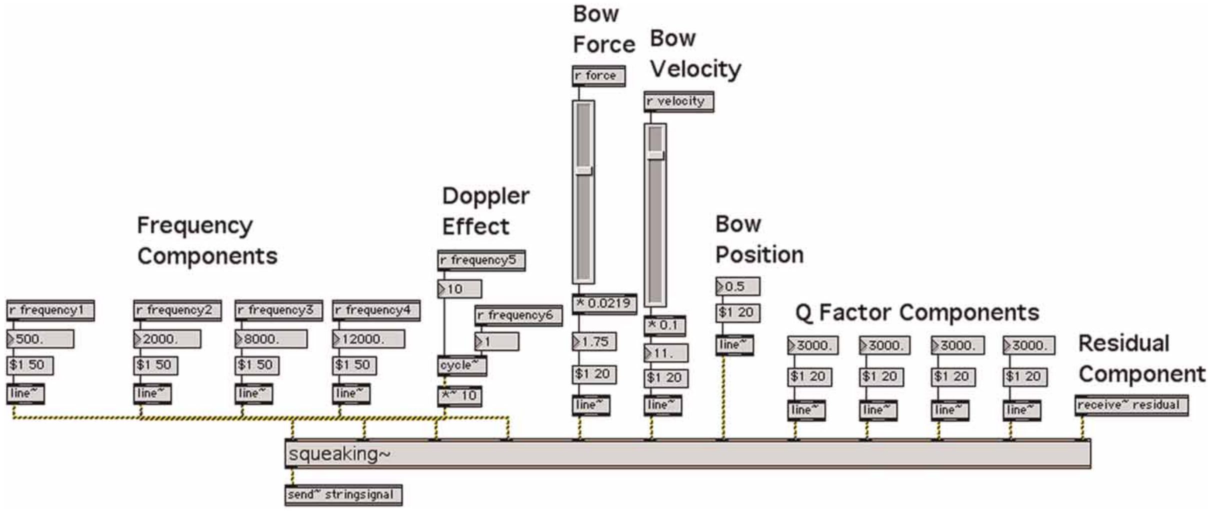

Figure 2. String model implemented in MAX/MSP as the *squeaking* ~ external object.

for a set of cyberstrings. The amplitudes of the piano strings control the changes in pressure and velocity of the virtual ones. The frequencies of the piano string are transposed to the extremities before they are induced to the cyberstrings so that the cyberinstruments produce pitches normally unavailable on the piano. Spectra of multiple virtual strings are further cross-fed in a closed network. In the process the cyberstring network gains a certain independence of the piano performance and produces indeterminate novel sonorities.

The cyberinstrument may be controlled externally or internally. In a situation of external control the pianist performs on the keys in normal mode without producing any pitch. The strings respond to the impulses provided by the piano as they do in the second movement. Later in the movement the cyberstrings develop into autonomously driven cyberinstruments through the analysis of one string's output and the cross-synthesising of it with another replica of itself. Thus the cyberstring functions both as an exciter and resonator. Some input parameters are still provided but the sonic separation of the cyberstring from the keyboard's input is transparent.

3.3 Bowed cyberstrings and cyberbars in *Revelations* (2005)

Revelations for circular toys, resonant plates and electronics primarily explores the sonorities of physical toys and virtual percussion instruments. It uses plastic superballs and glass marbles. Metal Bocci balls were used to control virtual maracas, guiro and bamboo chimes (Cook 1997). Bouncing, rolling and scraping the circular toys against the resonant plates excites unrealistically shaped virtual shakers. A bowed percussion cyberbar developed by Georg Essl and Perry Cook (Essl and Cook 2000) and a friction bowed cyberstring designed by Serafin (Serafin 2004) complement the scraping actions of physical rubber ball against hard surfaces. The complete set-up is shown in Figure 3.

The cyberstrings and cyberbars contribute to the timbral and temporal extension of the quickly decaying scrapping gestures of the physical plates, particularly the plastic ones. The combination of physical scrapping

Figure 3. Circular toys and a metal resonant plate set up in *Revelations*.

excitation with the reverberation of virtual instruments augments analog digital resonating structures. The composition is detailed in Kojs and Serafin (2007a).

3.4 Singing cyberbowl in *En Una Noche Oscura* (2006) and *In Secret* (2006)

The traditional Tibetan singing bowls, made of a seven-metal alloy are hand-hammered to produce desirable tones. Oral tradition dates the singing bowl back to 560–180 BCE in Tibet. Since then, the bowls have proliferated through the Buddhist temples, monasteries and meditation halls throughout the world. The bowls are used for musical performance, relaxation, meditation and healing purposes.

In a typical performance the bowl is rubbed along its rim with a wooden stick, which may be wrapped in a thin sheet of leather. Depending on the rubbing velocity and initial state of the bowl (i.e. certain modes may be already ringing), the performer may excite a multiplicity of modes.

The long decay time and frequency beatings are the characteristic features of the sound produced by the Tibetan singing bowl. Circular banded waveguides are the most suitable technique for simulation of the singing bowl. As explained in Essl et al. (2004), beatings can be implemented by detuning the banded waveguides. The friction model described in Serafin (2004) enables sustained interaction. Figure 4 shows the singing bowl model as implemented in MAX/MSP for real-time use.

En Una Noche Oscura involves the acoustic flute, violin, cello and piano and a singing cyberbowl. Each physical instrument is miked and its signal energises a different parameter of the same cyberbowl in MAX/MSP. In this way the ensemble of instruments collectively deforms the size and shape of the bowl. Mapping multiple instruments to a single virtual bowl generates parametrical situations non-existent in physical reality. Mapping assignment of a particular instrument to a particular cyberbowl parameter continuously changes. Thus, the physical instruments and cyberbowl construct a network analog-digital instrument.

The audio signals from the instruments are also fed into the bowl itself, which serves as a resonant filter and thus creates a virtual performance space. The virtual bowl allows for eight-channel spatialisation. A rotation algorithm incites a contrapuntal relationship between the parametrical mapping and spatial distribution.

The cyberbowl is parametrically deformed in real-time in this piece. Tapping and rubbing are the two primary cyberactions engaged in excitation of the cyberinstrument. The virtual space of the bowl is further colonised by the audio signal from the instruments. One can rarely hear the characteristic singing bowl sonorities as the cyberinstrument's identity is continuously extended. Figure 5 shows an example from *En Una Noche Oscura*.

In Secret for oboe and electronics also utilizes the singing cyberbowl. The oboist performs on an instrument without the reed for most of the piece. The performer's circular breathing, humming, whispering and enunciating the text in the instrument produce mostly noisy sonorities in the piece, which

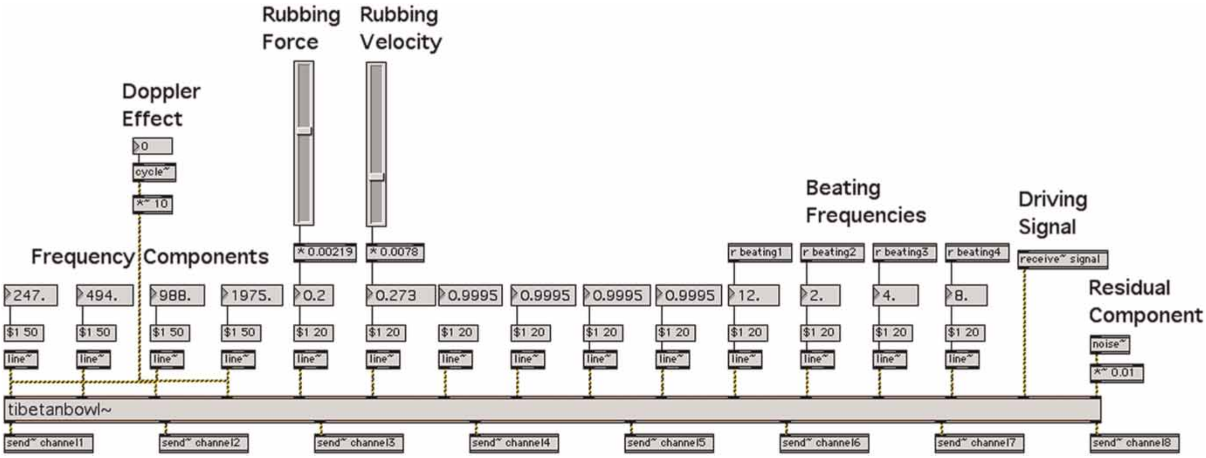

Figure 4. The eight-channel *tibetanbowl* ~ external object for real-time use in MAX/MSP.

presents a single gesture of pitch emerging from the coloured noise.

The oboe is amplified and its signal components also function as the controllers for the parameters of the singing cyberbowl in MAX/MSP. Key clicks, explosive outbursts and other gestures excite the cybrinstrument which complements the residual oboe sonorities with well-shaped frequency spectra. The tones extracted from the poem constitute a set of resonating frequencies for the virtual bowl. The cyberbowl enables fluent transitioning between the frequencies, which suggests the fluid deformation of the bowl's body. Changes in beating frequencies further impart the simulation of continuously changing materials.

The cyberbowl also acts as a resonating space in which the performance occurs. The eight-channel spatialised cyberbowl is further rotated in MAX/MSP, thus giving an impression of space evolving in a spiral. The composition layers the physical and virtual sonic spaces, with oboe and cyberbowl intertwining to create an augmented sonic reality.

3.5 The cyberfujara in *Air* (2006)

The fujara is an indigenous Slovakian folk instrument originating in the Great Moravian Empire in the 10th century (Macak 1995). The fujara is a wooden pipe 165–190 cm long and 3–5 cm across made of semi-hard wood from indigenous trees. The traditional Slovak fujara has three holes, although fujaras with as many as nine holes may be found in some Slovakian regions. A traditional three-hole fujara is displayed in Figure 6.

Initially the shepherds played the fujara to express solitude and the pastoralism in their quotidian life in the mountains. The solo folk songs performed on the fujara were often sustained and melancholic in nature. Over the centuries, players established groups of three to seven, performing music of a variety of moods and tempi. To these days, the fujara thrives in the Southwestern region of Detva and elsewhere.

Organologically the fujara is a bass recorder, meaning it can be most efficiently simulated by a one-dimensional digital waveguide (Smith 2004). Low-pass digital filters are used to model radiation and visco-thermal losses inside the bore of the instrument in the simulation. As in traditional flutes, the length of the long tube governs the fundamental frequency. The length control of the digital waveguide enables the simulation of fujaras

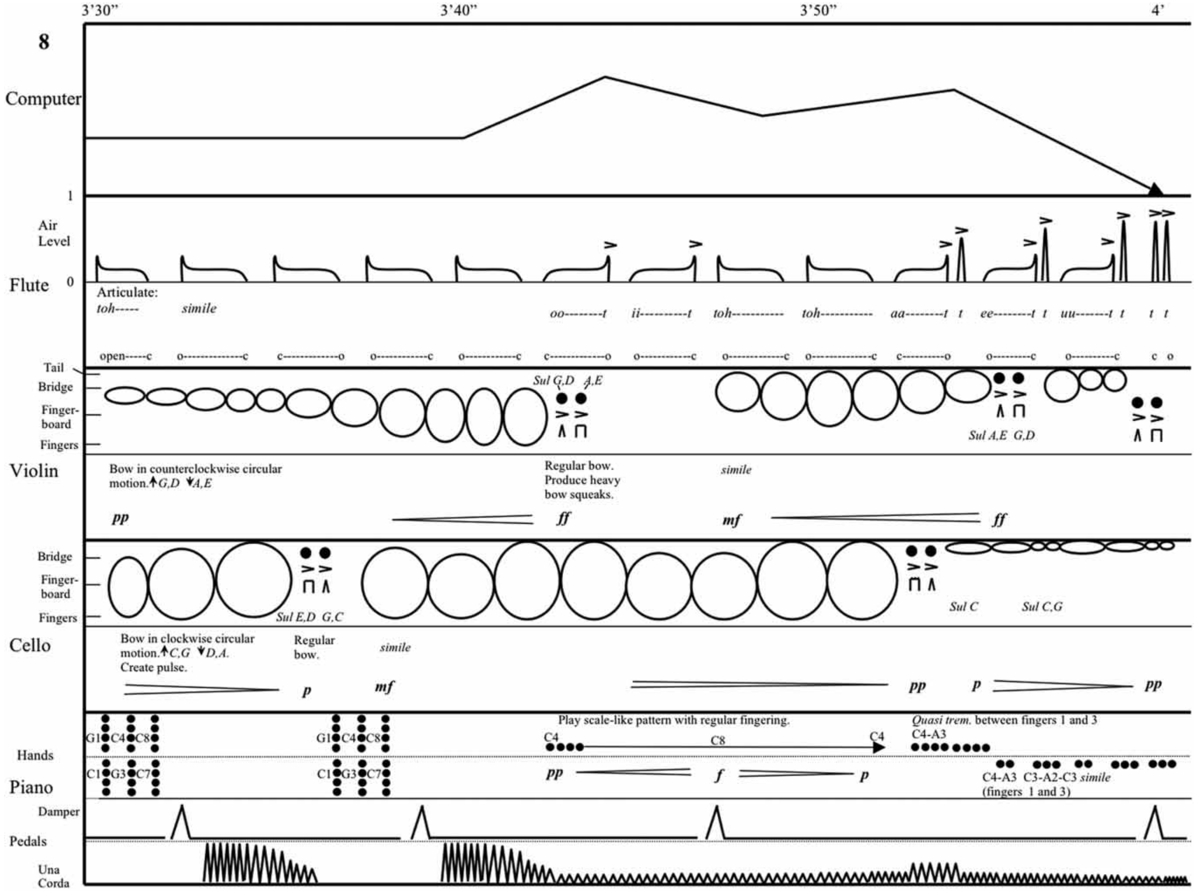

Figure 5. An example from the score of *En Una Noche Oscura*.

with a variety of registral ranges. The model is detailed in Kojs and Serafin (2006) and the diagram shown in Figure 7.

The composition *Air* presents a dialogue between physical fujaras and cyberfujaras. *Air* recontextualises an ancient musical instrument in our era. The physical fujara functions as a controller for six cyberfujaras in real-time in the composition. A microphone positioned close to the opening of the instrument transmits the audio signal to Max/MSP, where its pitch and amplitude are tracked by the *fiddle* ~ object (Puckette et al. 1998). The object works efficiently as the tracked tones show stable fundamental frequencies and amplitudes. In addition to the fundamental frequency, up to three higher sinusoidal components are extracted from the tone's spectrum. These are rescaled and mapped as the fundamental frequencies of the cyberfujaras.

The virtual fujaras extend the frequency range, amplitude envelope contour and duration and timbre of the physical instruments. The cyberinstrument further facilitates circular breathing, an effect that is impossible to achieve with the physical fujara.

Figure 6. Traditional Slovakian three-hole fujara in G.

3.6 Percussion cybermembrane in *To Where He Waited* (2006)

To Where He Waited (2006) for cello and electronics presents an investigation of the noisy sonorities that can be produced by the instrument. The electronic part uses a percussion cybermembrane. Scott Van Duyne and Julius O. Smith designed this cyberinstrument as a two-dimensional waveguide mesh (Van Duyne and Smith 1993). Dan Trueman ported the model to MAX/MSP (Trueman and DuBois 2005).

The cybermembrane presents a sonic barrier which is excited by the cello signal. The cello sound is heard only when it passes through this virtual wall. A number of membranes are tuned to the pitches derived from the musical letters of the fourth verse from John of Cross' *Dark Night*. The electronic part combines the real-time and pre-recorded sonorities of the resonating cybermembranes. While the membranes spectrally enrich the sustained cello sonorities, they accentuate the metallic character of strings on the pizzicato attacks. Figure 8 provides an example from the score.

3.7 Cyberflute in *Concealed* (2006)

Concealed explores flute sonorities that lie on the border of hearing. The concealed pitch in it is heard by the listener as the colour of timbre. While the flute mainly produces coloured noise, the cyberflute provides pitched materials.

The real-time cyberflute operates in MAX/MSP. Perry Cook and Gary Scavone originally implemented the waveguide flute model in the STK application (Cook 1992, Cook and Scavone 1999). Dan Trueman later ported the model to MAX/MSP as an external object *flute~* , a member of the PeRcolate library of external object for MAX/MSP (Trueman and DuBois 2005).

The signal of the flute performer functions as a controller for the cyberflute in real-time. The microphone tracks the signal and sends it to MAX/MSP, where it is simultaneously amplified, processed, and fed into the cyber-instrument. Blending the sonorities of physical and virtual instruments results in the creation of a unique analogue-digital instrument.

The cyberflute is characterised by a set of parameters such as breath pressure, jet angle, noise, vibrato frequency, vibrato gain and tone frequency. The cyberflute augments the sonorities of the physical flute by extending its registral and textural arenas. The cyberflute's frequencies imitate the pitches based on the musical letters from the second verse of St. John's *Dark Night*, which are registrally spread beyond the range limitations of any

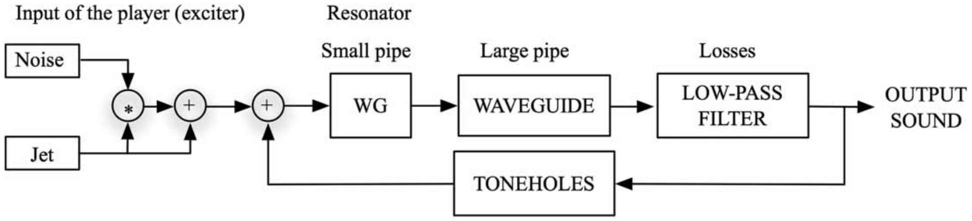

Figure 7. Block diagram of the fujara physical model.

physical flute, enabling the production of tones like G2 (98 Hz) and E9 (10548 Hz).

The sequences of frequencies are further controlled algorithmically to create temporal situations unplayable on the physical instrument, like increasing the rate of frequency change to 50 ms per event. The subsequent frequencies may be further positioned at the extreme ends of the spectra and performed with physically impossible dynamic forces.

3.8 Bowed cocktail cyberglasses in *Neither Stirred, Nor Shaken* (2007)

Neither Stirred, Nor Shaken composed for cocktail glasses, shakers, blenders and electronics engages physical actions such as stirring, shaking and mixing with everyday objects, sensors and cyberinstruments via physical modeling synthesis. In it three performers stir liquids and ice with metal

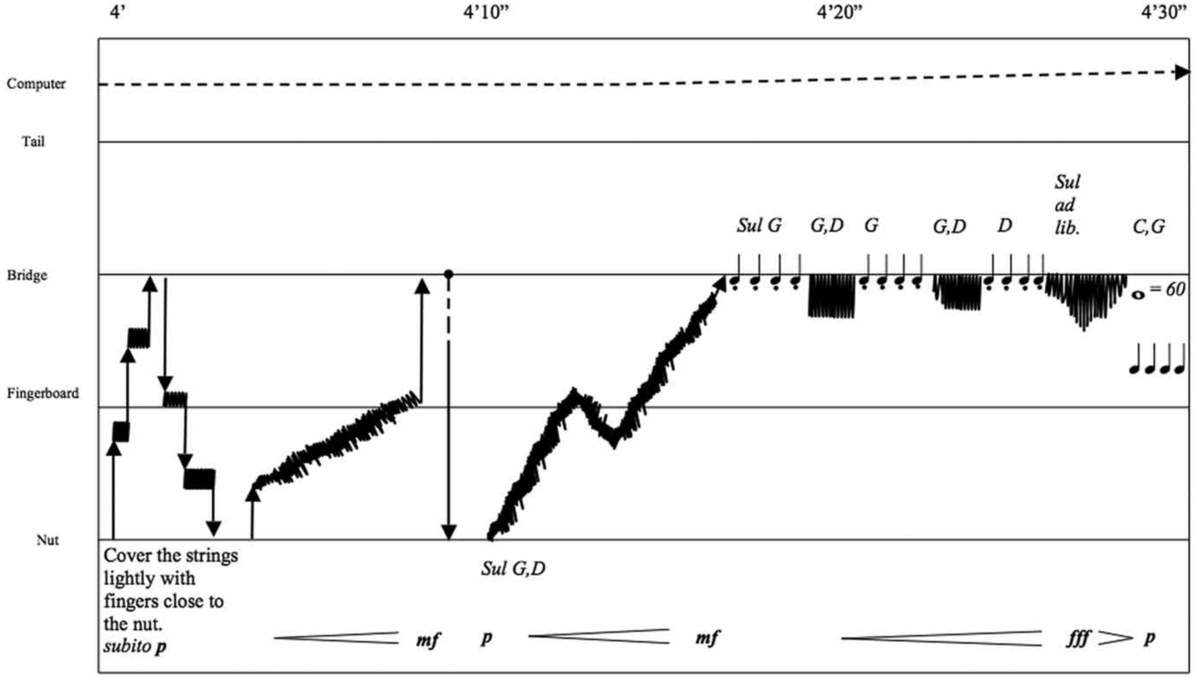

Figure 8. An example from *To Where He Waited*.

Figure 9. Complete setup of *Neither Stirred, Nor Shaken*.

spoons in highball cocktail glasses, shake their concoctions in metallic shakers; and mix them in electric blenders which are coupled with the cybershakers and cyberrattles and singing bowed cyberglasses in order to create rich timbral tableaux.

The cocktail glasses are modelled using an adaptation of the circular banded waveguide (Essl et al. 2004). Serafin's friction model simulates the interaction between a player's finger and the rim of the wineglass (Serafin 2004). As in the physical world the rubbed cocktail glass model shows a spectrum in which a single strong resonance prevails.

Neither Stirred, Nor Shaken utilises sensor technologies connected to the *Make Controller* board in the process of acquiring the data from the everyday objects (Making Things 2007). This board is connected to a computer running the MAX/MSP application via a USB cable, although other connections (e.g. Ethernet) are also possible. The setup for each player, which consists of a highball cocktail glass, a tall metal spoon, metal shaker, electric blender, ice, clear liquid, sensors and *Make Controller* board, is displayed in Figure 9[2].

Stirring, shaking and mixing actions excite bowed cyberglasses. The sustained resonances of the cyberinstruments complement the percussive sounds of the physical objects. The cyberinstrumental parameters such as resonant frequency, finger force, velocity and positions are continuously altered in order to imitate and augment the fluid nature of liquid materials.

4 Conclusion

Physical modelling syntheses such as digital waveguides, modal synthesis and mass-spring-damper algorithms have been widely used to simulate musical instruments, everyday objects and environmental phenomena. Due to their mathematical compactness, stability and real-time efficiency the digital waveguides are particularly useful in extending simulated originals beyond the limitations of the physical world, retaining timbral behaviour in a variety of registral and performance situations, and providing intuitive control over their parameters.

Most composers used such extended cyberinstruments to augment the timbral possibilities of existing instruments. The sense of augmented sonic reality has been generated most effectively when the physical and cyberinstruments meet in performance. The extended cyberinstruments have additionally capacitated virtual resonating spaces in which the performances occur.

Notes

[1] Smith's website (www-ccrma.stanford.edu/~ jos) is an outstanding resource for researchers and musicians interested in physical models and digital signal processing for music.

[2] This composition and its technology details are well described in Kojs and Serafin (2007b).

References

Borin, G., De Poli, G. and Sarti, A. (1992) 'Algorithms and structures for synthesis using physical models', *Computer Music Journal*, vol. 16, no. 4, pp. 30–42.

Cadoz, C. (2002) 'The physical model as metaphor for musical creation "pico..TERA", a piece entirely generated by physical model', *Proceedings of the International Computer Music Conference*, Gothenburg, Sweden.

Chafe, C. (2005) 'Oxygen Flute'. A computer music instrument that grows', *Journal of Computer Music Research*, vol. 34, no. 3, pp. 219–226.

Cook, P. (1992) 'A meta-wind-instrument physical model, and meta-controller for real-time performance control', *Proceedings of the International Computer Music Conference*, San Jose State University, USA, pp. 273–276.

Cook, P. (1997) 'Physically inspired sonic modeling (PhISM): synthesis of percussive sounds', *Computer Music Journal*, vol. 21, no. 3, pp. 38–49.

Cook, P. and Scavone, G. (1999) 'The Synthesis ToolKit (STK)', *Proceedings of the International Computer Music Conference*, Beijing, China, pp. 164–166.

Essl, G. and Cook, P. (2000) 'Measurements and efficient simulation of bowed bars', *Journal of the Acoustical Society of America*, vol. 108, no. 1, pp. 379–388.

Essl, G., Serafin, S., Cook, P. and Smith, J.O. (2004) 'Musical applications of banded waveguides', *Computer Music Journal*, vol. 28, no. 1, pp. 51–63.

Jaffe, D. and Smith, J. O. (1983) 'Extensions of the Karplus-Strong plucked string algorithm', *Computer Music Journal*, vol. 7, no. 2, pp. 56–69.

Karplus, K. and Strong, A. (1983) 'Digital synthesis of plucked string and drum timbres', *Computer Music Journal*, vol. 7, no. 2, pp. 43–55.

Kojs, J. and Serafin, S. (2006) 'The fujara: the physical model of the bass pipe instrument in an interactive performance', *Proceedings of the International Computer Music Conference*, New Orleans, USA, pp. 540–543.

Kojs, J. and Serafin, S. (2007a) 'Everyday objects in interactive electroacoustic compositions', *Proceedings of Sound and Music Computing Conference*, Lefkada, Greece, pp. 338–344.

Kojs, J. and Serafin, S. (2007b) 'Stirring, shaking, and mixing: musicalizing everyday actions', *Proceedings of the International Computer Music Conference*, Copenhagen, Denmark, pp. 240–244.

Kojs, J., Serafin S. and Chafe, C. (2007) 'Cyberinstruments via physical modeling synthesis: compositional applications', *Leonardo Music Journal*, vol. 17, pp. 61–66.

Macak, I. (1995) *Dedicstvo hudobnych Nastrojov (The heritage of musical instruments)*, *Slovenske Narodne Muzeum a Hudobne Muzeum*, Bratislava, Slovakia.

Making Things (2007) *Make Controller* available at www.makingthings.com

McIntyre, M.E., Schumacher, R. T. and Woodhouse, J. (1983) 'On the oscillations of musical instruments', *Journal of the Acoustical Society of America*, vol. 74, no. 5, pp. 1325–1345.

Puckette, M. (1996) 'Pure data', *Proceedings of the International Computer Music Conference*, Hong Kong University of Science and Technology, China, pp. 269–272.

Puckette, M. (2002) 'Max at seventeen', *Computer Music Journal*, vol. 26, no. 4, pp. 31–43.

Puckette, M., Apel, T. and Zicarelli, D. (1998) 'Real-time audio analysis tools for Pd and MSP', *Proceedings of the International Computer Music Conference*, University of Michigan, USA, pp. 109–112.

Scavone, G. and Smith, J. O. (1997) 'Digital waveguide modeling of woodwinds toneholes', *Proceedings of the International Computer Music Conference*, Aristotle University, Thessaloniki, Greece, pp. 260–263.

Serafin, S. (2004) 'The sound of friction: real-time models, playability and musical applications', PhD thesis, Stanford University, USA.

Serafin, S. and Kojs, J. (2005) 'Computer models and compositional applications of plastic corrugated tubes', *Organized Sound*, vol. 10, no. 1, pp. 67–73.

Serafin, S., Wilkerson, C. and Smith, J. O. (2002). 'Modeling bowl resonators using circular waveguide networks', *Proceedings of* the *Conference on Digital Audio Effects*, Hamburg, Germany, pp. 117–121.

Smith, J. O. (1992) 'Physical modeling using digital waveguides', *Computer Music Journal*, vol. 16, no. 4, pp. 74–91.

Smith, J. O. (2004) 'Virtual acoustic musical instruments: review and update', *Journal of New Music Research*, vol. 33, no. 3, pp. 283–304.

Stiefel, V., Trueman, D. and Cook, P. (2004) 'Re-coupling: the uBlotar synthesis instrument and the sHowl speaker-feedback controller', *Proceedings of the International Computer Music Conference*, Miami, USA, pp. 547–554.

Sullivan, C. (1990) 'Extending the Karplus-Strong algorithm to synthesize electric guitar timbres with distortion and feedback', *Computer Music Journal*, vol. 14, no.3, pp. 26–37.

Trueman, D. and DuBois, L. (2005) *PeRColate.* Version 0.9b6, [online], http://music.columbia.edu/PeRColate, accessed 10 January 2008.

Van Duyne, S. and Smith, J.O. (1993) 'Physical modeling with the 2-Ddigital waveguide mesh', *Proceedings of the International Computer Music Conference*, Waseda University, Japan, pp. 40–47.

Zicarelli, D. (1998) 'An extensible real-time signal processing environment for Max', *Proceeding of the International Computer Music Conference*, University of Michigan, USA, pp. 463–466.

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