Force Feedback Gesture Controlled Physical Modelling Synthesis

David M Howard
Media Engineering Research Group
Department of Electronics
University of York, Heslington, York
YO10 5DD, UK
+44 1904 432405
dh@ohm.york.ac.uk

Stuart Rimell
Media Engineering Research Group
Department of Electronics
University of York, Heslington, York
YO10 5DD, UK
+44 1904 432407
smr12@ohm.york.ac.uk

Andy D Hunt
Media Engineering Research Group
Department of Electronics
University of York, Heslington, York
YO10 5DD, UK
+44 1904 432375
adh@ohm.york.ac.uk

ABSTRACT

A physical modelling music synthesis system known as ‘Cymatic’ is described that enables ‘virtual instruments’ to be controlled in real-time via a force-feedback joystick and a force-feedback mouse. These serve to provide the user with gestural controllers whilst in addition giving tactile feedback to the user. Cymatic virtual instruments are set up via a graphical user interface in a manner that is highly intuitive. Users design and play these virtual instruments by interacting directly with their physical shape and structure in terms of the physical properties of basic objects such as strings, membranes and solids which can be interconnected to form complex structures. The virtual instrument can be excited at any point mass by the following: bowing, plucking, striking, sine/square/sawtooth/random waveform, or an external sound source. Virtual microphones can be placed at any point masses to deliver the acoustic output. This paper describes the underlying structure and principles upon which Cymatic is based, and illustrates its acoustic output.

Keywords

Physical modeling, haptic controllers, gesture control, force feedback.

1. INTRODUCTION

The incorporation of computer technology in electronic musical instrument has enabled musicians to push back the creative boundaries within which they work, but despite enjoying the resulting freedom from physical constraints, musicians are still searching for virtual instruments that come closer to their physical counterparts. The widespread availability of gestural controllers which now incorporate a tactile element by means of proprioceptive force feedback, following in the wake of PC gaming developments, offers a cost effective route to restoring the musician’s sense of working with a true physical instrument in the natural world. The acoustic output from computer instruments is often described as ‘cold’ or ‘lifeless’ whereas that from real instruments may be described as ‘warm’, ‘intimate’ or ‘organic’. These criticisms can be addressed in two ways: (i) by using physical modelling to create organic sounds that more closely resemble those of physical causality, and (ii) by creating new user interfaces that enable musicians to interact with the computer in more intuitive and intimate musical ways.

A new instrument, known as ‘Cymatic’, is described in this paper that incorporates both of these approaches to create an instrument which provides an immersive, organic and tactile musical experience that is more commonly associated with acoustic instruments and rarely found with computer-based instruments. Cymatic takes inspiration from physical modeling sound synthesis environments such as TAO [1], Mosaic [2] and CORDIS-ANIMA [3], through the use of resonating structures that can be interconnected to create complex and musically versatile virtual instruments playable in real-time using one or more acoustic excitation methods.

Musicians interact with Cymatic’s virtual instruments via tactile and gestural interfaces, thereby providing a route to enabling them to interact with the computer in more intuitive and intimate musical ways. In the virtual domain, the player is physically detached from the sound source and therefore is interacting with it indirectly via interface peripherals such as a mouse, MIDI keyboard or musical instrument controller. Second to audition itself, the haptic senses provide the most important means for observing and interacting with the behaviour of musical instruments [4]. Developments in computer-based musical instruments have prioritised visual stimuli over tactile control, with the result that the haptic senses have been left seriously undernourished. It is only possible to realise complex and realistic musical expression when both tactile (vibrational and textural) and proprioceptive cues are available in combination with aural feedback [5, 6]. Previous attempts to rectify this unsatisfactory situation include: electronic keyboards that have a ‘feel’ close to a real piano [7] the provision of tactile feedback [8], haptic feedback bows that simulate the feel and forces of real bows [9], and the use of finger fitted vibrational devices in open air gestural musical instruments [10].

Existing haptic control devices are generally one-off devices that are restricted to implementation with specific computer systems, and are thereby inaccessible to the musical masses. In contrast, Cymatic exploits the musical interface potential of inexpensive and widely-available PC gaming devices, as its real-time gestural control and haptic feedback is provided by a force feedback joystick and a tactile feedback mouse.

2. Overview of Cymatic

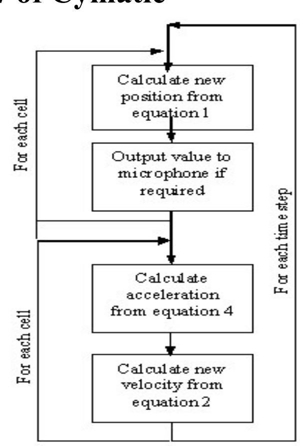

Figure 1: Schematic depicting the flow of operations in Cymatic’s core mechanics functions

Cymatic is implemented in C under Windows on a standard PC machine. It utilises the mass-spring paradigm of physical modelling to synthesise resonating structures in real time, and the calculations are carried out for each mass cell in terms of updating its position, velocity and acceleration based on the forces acting on that cell. For real-time operation, this set of calculations has to be completed for every cell in the instrument within time *dt* (the reciprocal of the sampling rate selected), otherwise audible output clicks are likely to result since the output waveform will not be fully defined. It can be shown that [11] the position (x), velocity (v) and acceleration (a) can be calculated from equations 1, 2, and 3 respectively.

$$x(t+dt) = x(t) + v(t + dt/2)dt \qquad (1)$$

$$v(t + dt/2) = v(t - dt/2) + a(t)dt \qquad (2)$$

$$a(t) = (1/m)(k\sum (p_n - p_0) - \rho v(t) + F_{external}) \qquad (3)$$

Where: k is the spring constant, m is the mass of the cell, ρ *is the viscosity as given by the damping parameter of the cell,* $F_{external}$ *is the force on the cell from any external excitations e.g. plucking or bowing,* p_n *is the position of the* n^{th} *neighbour, and* p_0 *is the position of the current cell.*

Cymatic is implemented in C++ on a PC machine. It performs all the calculations required to run the model in a core mechanics function as illustrated in figure 1. The new cell position, velocity and acceleration values are calculated from equations 1, 2, and 8 respectively.

Users design instruments by means of an intuitive graphical user interface (GUI) to create resonant structures of irregular shapes and multiple dimensions. These can be interconnected (any point mass on one structure to any point mass on another structure) to form highly complex virtual instruments. Figure 2 shows an example complex Cymatic instrument. Virtual excitation mechanisms are available (bowing, plucking, oscillators and live-audio input) which can be applied to any point mass within the instrument under real-time or off-line control. Any of the physical parameters can be altered in real time as desired. During synthesis, real-time animation of the instrument is available to provide visual feedback of instrument vibrations. Control over instrument parameters and excitation functions is gestural via a force feedback joystick and force feedback mouse.

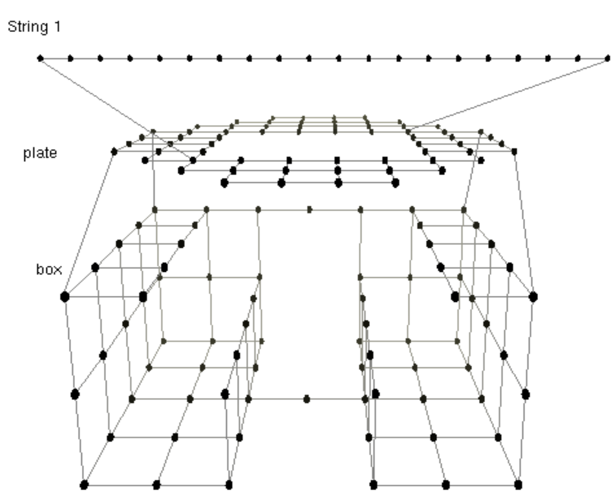

Figure 2: An example complex Cymatic instrument consisting of an interconnected string, membrane and solid.

The resulting sound can be heard by placing any number of *virtual microphones* that can be placed at user-defined points on the instrument (see figure 3). The output is the sampled displacement of the mass-spring cell to which it is attached. A selection of standard sampling rates from 96kHz to 8kHz are available, giving the user scope to trade off frequency resolution against the number of point masses that can be incorporated in the instrument for real-time operation.

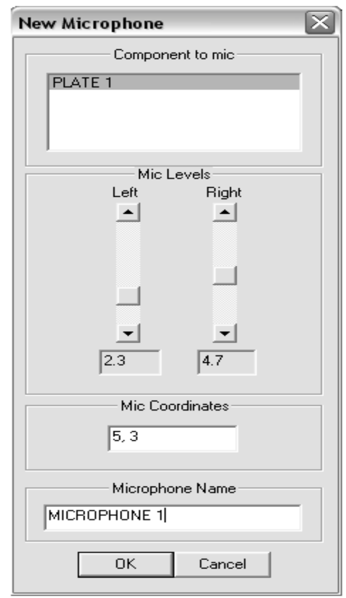

Figure 3: Cymatic's dialog box enabling placement of virtual microphones at arbitrary cell coordinates

Figure 4 shows a series of time frames from Cymatic's animated GUI interface to illustrate the motion of a bowed string. The animations provide immediate feedback as to the authenticity of the physically modelled excitations in terms of the design intention and the interaction between various elements.

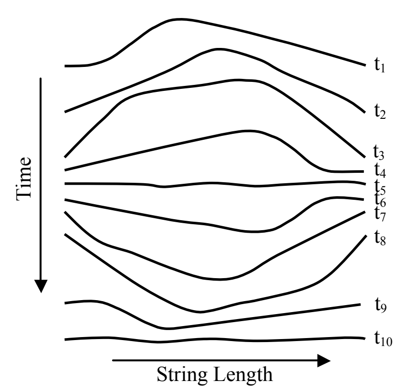

Figure 4: Time snapshots from a Cymatic animation showing Helmholtz motion of the bowed string model

Due to the mass-spring nature of the physical modelling process, the instrument can be modified in real-time during synthesis. For example, excitations and virtual microphones can be moved in real-time, 'virtual scissors' can be applied to strings, membranes or solids, and mass or spring parameters can be adjusted.

3. Real-Time Control

Real-time control of Cymatic is currently achieved using the joystick and mouse to vary the physical parameters within the instrument components, including mass, tension and damping, excitation force and velocity, excitation point and virtual microphone point.

Cymatic's main controllers are a Microsoft Sidewinder Force Feedback Pro Joystick and a Logitech iFeel mouse. The joystick offers four degrees of freedom (x-movement, y-movement, z-twist movement and a rotary "throttle" controller) and eight buttons. It also provides tactile and proprioceptive feedback with a high degree of customizability, boasting the potential to output six forces simultaneously. Force feedback implementation for Window's devices is normally achieved via DirectX and the 'Immersion Foundation Classes.' The Microsoft Sidewinder Force Feedback Pro joystick receives its force instructions via MIDI through the combined MIDI/joystick port on most PC sound cards. Cymatic can stimulate the joystick's haptic capabilities by simply outputting the appropriate MIDI messages.

The Logitech iFeel mouse is a simple optical mouse which implements Immersion's [12] iFeel technology, containing a vibrotactile device to produce tactile feedback over a range of frequencies and amplitudes. It offers two degrees of freedom and three buttons. Stimulating the iFeel mouse's tactile feedback is achieved through Immersion's, "Immersion Touchsense Entertainment" software which converts any audio signal to tactile sensations on the iFeel mouse. The parameter assigned to each controller function is fully customizable so the controllers can be adapted to the type of instrument or excitation method that Cymatic is running through arbitrary mapping by the user.

The Microsoft joystick can simulate a wide range of time- and position-based haptic sensations. Time-based effects include periodic oscillations of a variety of waveforms and a wide range of amplitudes and frequencies (from 1Hz to approx 300Hz). Constant forces, pulses and recoils also come under this category. Position-based effects include sensations of friction, inertia, solid surfaces and damping as well as spring like forces which increase or decrease as a function of the displacement of the joystick handle. The forces are identified by the joystick as system-exclusive messages and can be played, stopped and altered parametrically in real-time with MIDI control change and aftertouch messages.

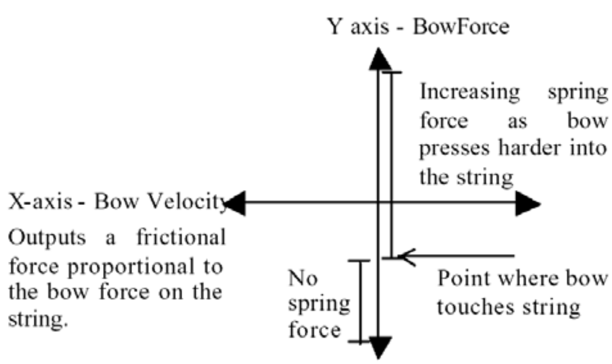

Figure 5: The haptic mapping of the joystick for Cymatic's bowed string model

Using these methods it is possible to design haptic sensations to suit the instrument and excitation type running on Cymatic. Figure 5 shows the haptic mapping for a Cymatic bowed string, in which the Y axis of the joystick is mapped to the force of the bow and the rate of change of the x-axis is mapped to the velocity of the bow. The user will feel no force until the virtual bow contacts with the string, after which the more force placed upon the string, the greater the force that is felt. A friction force in the x direction will also increase with respect to increasing the force placed on the string. The iFeel mouse is useful to simulate the velocity of the virtual bow while the joystick Y-axis takes care of the force parameter. This ensures that the user has to provide energy to the instrument via a gestural input in order to achieve an output. Other controller functions can be used to alter different parameters e.g. the 'twist' function of the joystick can change the tension of the string to be used as a vibrato effect and the 'throttle control' can be mapped to the bow position on the string, microphone position etc. A periodic force related to the amplitude and frequency of the audio output is felt through the iFeel mouse and the joystick's handle.

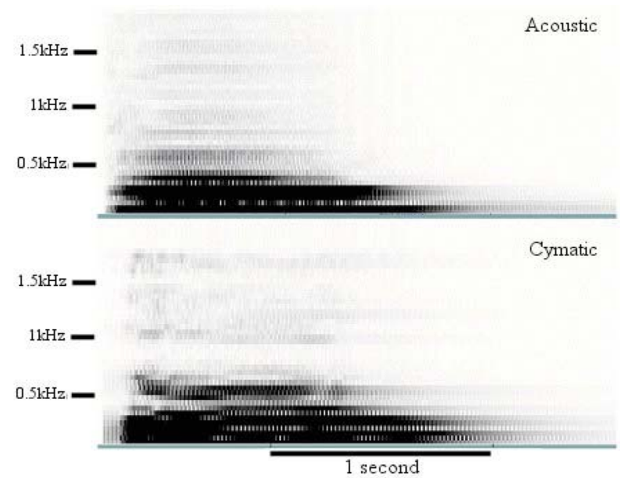

Figure 6: Spectrograms of the outputs from an acoustic double bass (upper) and a Cymatic bowed virtual instrument tuned to the same pitch.

Figure 6 enables the acoustic outputs from Cymatic and an acoustic double bass to be compared spectrographically, illustrating something of the potential organic nature of the Cymatic output sound. This is one of the key features of physical modelling. The Cymatic instrument has been bowed and its string set to produce the same fundamental frequency as that obtained from the acoustic double bass to enable comparison. There are clear similarities between the nature of the note onset and offset in each case, and it should be remembered that every note played on a Cymatic virtual instrument will be acoustically subtly different since each will have its origins in a unique gesture. Haptic and gestural mappings can be readily implemented to suit the individual instrument's needs.

4. Discussion

Cymatic was conceived with the desire to create new sounds through the use of new instruments, which may not be physically realisable in the real world, and to provide the player with a more engaging musical experience when performing with the instrument. The use of a physical modeling paradigm enables intuitions gained through training and performance with acoustic instruments to be immediately transferred to Cymatic instruments. The addition of tactile feedback reinforces the available visual and aural feedback cues, helping the player to develop internal models that are physically rooted in the manner in whcih the instrument responds to gesture.

Cymatic made its concert debut in December 2002 to universal audience acclaim at a public performance in York in a specially written piece by Stuart Rimell for a small (13 strong) SATB choir and Cymatic. Here the choir provided a backdrop over which a three sheet Cymatic instrument performed an obbligato. Extracts from this piece are available at [13].

Cymatic provides a new environment within which new musical instruments can be implemented, explored, and interacted with in live performance and composition. Only a very small subset of the potential possibilities has been explored to date, and next steps will focus on the creative side in an exploration of Cymatic's wider timbral potential. Cymatic instrument possibilities have the potential to feed musical imagination for a considerable time to come.

5. ACKNOWLEDGMENTS

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