Capturing Kinetic Wave Demonstrations for Sound Control

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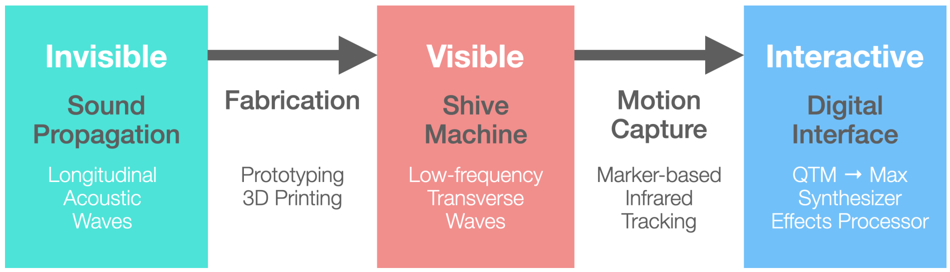

Figure 1: Workflow of conversions afforded by our digital toolset. Wave propagation, often invisible to the eye, is made visible and tangible via kinetic assemblies. Motion tracking is then used to transform these assemblies into a digital interface for flexible sound control.

ABSTRACT

In musical acoustics, wave propagation, reflection, phase inversion, and boundary conditions can be hard to conceptualize. Physical kinetic wave demonstrations offer visible and tangible experiences of wave behavior and facilitate active learning. We implement such kinetic demonstrations, a long spring and a Shive machine, using contemporary fabrication techniques. Furthermore, we employ motion capture (MoCap) technology to transform these kinetic assemblies into audio controllers. Time-varying coordinates of MoCap markers integrated into the assemblies are mapped to audio parameters, closing a multi-sensory loop where visual analogues of acoustic phenomena are in turn used to control digital audio. The project leads to a pedagogical practice where fabrication and sensing technologies are used to reconstitute demonstrations for the eye as controllers for the ear.

KEYWORDS

musical acoustics, digital fabrication, augmented reality, sonification, motion capture, sonic interaction design, music education

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1 INTRODUCTION

Through sensing, encoding and data processing, digital tools continue to support rapid conversions between media and their corresponding sensory channels. Stimuli devised for the eye can be quickly recast for the ear or vice versa and audio waveforms can in turn be materialized as corresponding textures for tactile exploration using digital fabrication. These tools accelerate the rate at which we transcode information for novel mediations. In this project, they specifically afford the rapid exploration of an instrument of acoustic science as one for creative sound control contributing to the dialogue of science and art through their instrumental extensions.

In this paper we describe such a practice where well established kinetic demonstrations used for acoustic visualization are captured to drive sound synthesis for musical explorations. We see this as a particularly compelling activity for students of music and musical acoustics with dual interests in understanding the physics behind musical sound as well as in making controllers and instruments to organize those sounds.

We begin by discussing how recent developments in digital fabrication facilitate new creative workflows and learning experiences. We then describe a case study where acoustic phenomena invisible to the eye are made not only tangible but also interactive as depicted in Fig. 1. We then offer the implementation details of a pilot experiment with a long spring and a Shive machine, both transformed to digital interfaces for sound control. Examples are provided of how these instruments can be used to control various synthesis parameters and audio effects.

2 MAKING IN EDUCATION

The digital revolution in production, often associated with audiovisual media, extends into the domain of things with desktop manufacturing. This change emerged with Neil Gershenfeld's early course at MIT called "How to Make (almost) Anything" and his prediction that such practices would become increasingly integrated into education. In the last decade, we have seen widespread efforts within institutions to ensure that this unique active learning opportunity is combined with conceptual learning in a variety of subjects [8].

Gershenfeld coined the term fab-lab, a maker-space defined by the presence of 3D printers, laser and vinyl cutters as well as desktop computer controlled mills for printed circuit board design. Although safety training for these tools is still critical, liabilities associated with traditional manual mills and lathes are foregone as our interaction is increasingly mediated by software control. If the bar of entry is lowered, so is the cost of making complex geometries through the very nature of additive manufacturing.

Additive manufacturing (or 3D printing) dissociates cost from complexity by reducing a given model to a series of 2D layers deposited sequentially along the vertical axis. Otherwise difficult interior geometries are achieved through this layer-wise deposition of cross sections. This frees up the designer to try out otherwise onerous ideas, to augment existing forms, and explore alternative designs without requiring an industrial research budget. Whether it is novel designs, or antiquated ones that serve to reinforce our understanding of the history of technology[7], computer assisted fabrication has made physical making pervasive as a mode of problem solving and inquiry in education.

Such making gives rise to material problem-solving opportunities that supplement and reinforce conceptual knowledge, an indispensable component of learning associated with Seymour Papert and the constructionist movement in education [3]. Access to precision manufacturing initiates a qualitative change in the object from the perspective of the maker, who now participates in the design process, encountering potential alternate designs, shortcuts and revisions. Indeed, in the making of the Shive machine, the authors were positioned to consider its design and imagine alternative applications which led to the research reported here.

3 FABRICATING WAVE DEMONSTRATIONS

Édouard-Léon Scott de Martinville's Phonautograph, a device predating Edison's phonograph by twenty years, was the first mechanism to capture visual residues of airborne sound. The Phonautograph's capacity to playback that sound, however, had a century delay before researchers at Berkeley could finally 'read' this antique media using laser scanning [2].

This example provokes the question, what are other opportunities to use contemporary tools of scanning, capture and data mapping to lend sound to its visual analogues? The history of acoustics is full of kinetic devices used to exhibit wave phenomena to the eye. Our contemporary digital tool-set can be used to flexibly explore these devices as inputs to sound synthesis parameters.

It may be argued that such kinetic demonstrations are made obsolete by computational physical modelling and software simulations. However, it is hard to match physical demonstrations in their tactile, immediate and convincing illustration of physical phenomena under study. These tangible demonstrations continue to serve an important role in acoustics education, where wave behavior is decelerated to the slow temporal resolution of the eye [1, 9]. Such examples range from the common experience of radiating waves in water to the behavior of extension springs, pendulums and ingenious mechanisms such as the Shive machine and Charles Wheatstone's wave machine that demonstrated the polarization of wave forms [4].

As an initial experiment, We started by adding motion capture markers to a long extension spring, an object commonly used in the acoustics classroom to illustrate the behavior of a pressure wave, its phase change under different boundary conditions and the resulting wavelength of harmonically related standing waves. The behavior of the long spring, excited within its elastic limit, can therefore be used by analogy to unravel auditory phenomena and causes. For example, closing a pipe while it is sounding produces an octave shift down, yet the cause of this somewhat discrete change cannot be easily grasped aurally. Conversely, When observing a transverse pulse moving down a spring and undergoing inversion as it reflects off its termination point, the phase change on which the wavelength depends becomes easily grasped. These kinetic materials are compelling demonstrations of causes if also symptomatic of a longstanding bias for visually corroborated knowledge [5]. By adding markers to the spring and the Shive machine for motion capture, and subsequently mapping the coordinates to sound, we are able to dramatize the process by which a scientific tool, devised to understand sound, in turn influences the invention of new musical instruments or controllers.

4 THE SHIVE MACHINE

We also integrated markers into a Shive machine, a kinetic wave mechanism that converts torsional vibrations of a wire into a transverse pattern of movements along rods distributed perpendicular to that wire. This mechanism creates very slow waves for visual inspection. The rods serve both as levers that initiate and amplify the wave pattern.

The Shive machine was invented by John Northrup Shive at Bell Labs and is the basis of his short textbook, *Similarities in Wave Behavior*. The first chapter of this book is entitled,"Building a Shive Machine", where he stresses that all subsequent concepts (i.e., reflection, superposition, standing waves, impedance matching, loaded lines, boundaries, and wave filters) should be addressed through demonstrations and active learning on this machine. In an approach that is undergoing a resurgence in education, Shive asked his students to first make an instrument and then use it to observe and think about principles [10]. With fab-labs increasingly integrated into schools, universities and public libraries, it behooves us to continue to revive this maker approach to acoustics education.

4.1 Fabrication

To construct the Shive machine we combined 3D printing with readily available materials. A wire was wound through a pulley and turned back on itself in parallel, anchored to either end of a metal pipe. The wire was put in tension with a turn-buckle, suspended over and threaded through 3D printed bridges and joints that also serve to hold the array of rods (Fig. 3).

The 3D printed components were modelled in OpenScad, an open source script based computer-aided design software that uses constructive solid geometry [6]. The components were then printed in

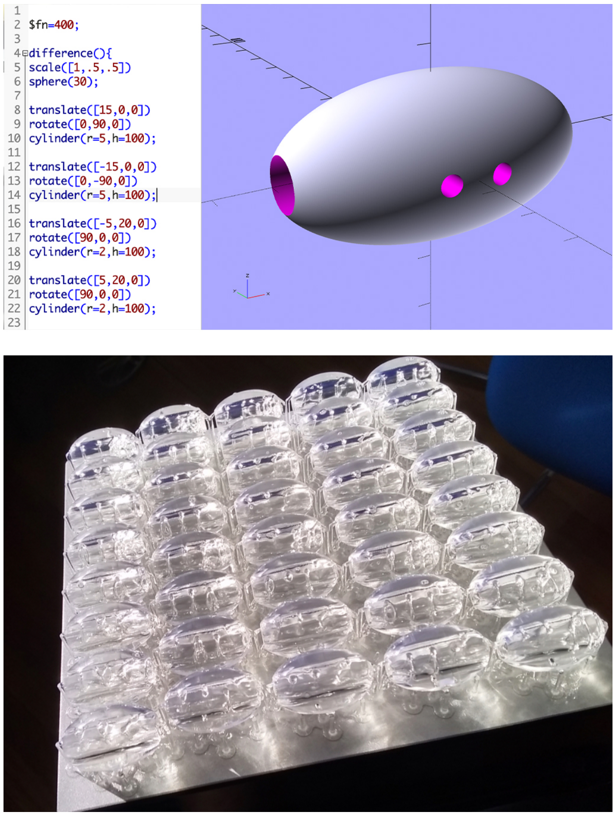

Figure 2: Top: OpenScad model joints through which the parallel wires of the Shive machine travel. Bottom: Batch of joints printed on Form 2 Resin-based Stereolithography Printer.

Figure 3: Top: Shive machine being driven by hand. Bottom: Close-up of the Shive machine displaying the array of beads holding parallel wires and perpendicular rods.

batches on a Form2 resin-based 3D printer. This method of making a Shive machine would have been unwieldy without 3D printing, which enables the fabrication of identical batches of precision joints seen in Fig. 2.

5 MOCAP AND SONIC INTERACTION

A 16-camera Qualisys Motion Capture (MoCap) System was used to achieve a sensing diameter of 5 meters within the Davis Technology Studio seen in Fig. 4. Qualisys is a marker-based infra-red tracking system that records at a sampling rate of 100Hz. Markers were embedded within the coils of the spring as well as attached to each rod on the Shive machine for a total of 48 markers. In a typical MoCap application, such as capturing human movement, the mass of a marker is negligible. In this case, however, the markers served a dual function as tracking points and masses that increase the magnitude of the oscillation.

Interactions on the spring and Shive machine ranged from exciting the mechanism at a constant rate to trials where we increased the frequency incrementally over time, allowing us to capture a harmonic series of standing waves. Each recording was later reviewed in order to manually label each trajectory, delete unnecessary data and fill the gaps between frames where occlusions occurred.

5.1 Wave Demonstration as a Digital Interface

The Qualisys Track Manager (QTM) software streams MoCap data via Open Sound Control. Using the *modosc* library for Max [11], we mapped the 3D coordinates of each marker to audio parameters.

Using the recorded captures of the Shive machine and spring we were able to work on different sound synthesis algorithms without having to set up the devices each time. One capture in particular was used repeatedly, where we accelerated the frequency incrementally. In this capture the device starts oscillating at its fundamental frequency and moves to higher harmonics over time.

The waves of the spring and Shive machine correspond to subsonic frequencies. In audio synthesizers, such low-frequency oscillators (LFOs) are used to control a range of parameters including pitch and amplitude (i.e. for vibrato and tremolo respectively). In the capture, we could observe that the amplitude of the wave was represented by the movement of each marker along the Z axis (height) with full excursions at the anti-nodes of the standing waves. To make a simple LFO would only require one marker moving along this vertical axis. Considering our access to an aggregate of points, we conceived of two digital control schemes described below. All the demonstrations referenced here can be viewed at the YouTube link below. [1]

[1] https://bit.ly/3gENS4d

5.1.1 Synthesis controller. In our first experiment, the vertical coordinates of the markers controlled the frequencies of individual sine-wave oscillators in a range between 300-1000Hz (see videos 1 and 2). With the first harmonic (i.e. when all the markers move in the same direction), the result of the mapping was a unified sweeping tone. With additional higher harmonics it became harder to discern the wave behavior from the sound alone. To mitigate this ambiguity, we assigned different pitches from a major scale to each sine wave with the markers controlling the amplitude of the corresponding sine wave (see videos 3 and 4).

Although our main goal was to conduct a general exploration of such devices as audio controllers, we were also interested in how certain mappings varied as auditory displays; that is, how mappings revealed to the ear different things about the waveform and assembly. In general, an asymmetrical mapping was better suited to aurally discern the array of markers and their individual contributions. Conversely, redundancies in the mappings created fused auditory events with in-phase marker pairs distributed along the wave. These fusions were tightly indicative of the resonances of the system and therefore reinforced aurally its physical tendencies.

We also explored using the zero crossings for each marker to trigger enveloped tones arranged in various scales (see videos 5 through 8). Although these recordings often represent alternate mappings to the same wave sequence, recognition of the interaction is to some degree held constant from the auditory perspective given the ears refined temporal resolution. Again, we observed that the markers are harder to discern when mapped to symmetrical scales, such as chromatic, whole tone and diminished scales, due to redundancies and fusions within resonances.

5.1.2 Spectral Tremolo & Spectral Delay. We also used the pfft object in Max to perform frequency-domain audio processing with a total of 16 bins, with each bin corresponding to a range of 1378 Hz. In a one-to-one mapping approach, the amplitude of each bin was mapped to each marker's vertical coordinates to achieve a spectral tremolo effect. We applied the effect to both pink noise and piano performance and experimented with both unipolar and bipolar mappings. With unipolar mapping, where the minimum vertical coordinate of the marker was mapped to zero and the maximum was mapped to unity gain, we observed a more pronounced amplitude modulation effect whereas the bipolar mapping, on account of the doubled rate of modulation, created a filter-sweep effect. Due to the broadband frequency content, the modulation effects on pink noise were also more pronounced than on the piano performance (see videos 9 to 16).

In the spectral delay implementation,in addition to controlling the amplitude for each of the 16 bins, the markers also controlled the delay time (0-1000 ms) and the feedback multiplier (0-1) for the corresponding bins. Using a one-to-many mapping approach, we produced three examples by mapping the height of each marker to delay time; delay time and feedback; and delay time, feedback and gain (see videos 17-22).

6 CONCLUSION

This project initiates a practice we will continue to develop where kinetic demonstrations of wave phenomena are captured as interfaces for sound control. We see this practice as foregrounding and accelerating a longstanding relationship between instruments of musical acoustics and those of music, with particular relevance for students and practitioners who study both. We use a full gamut of digital tools, from computer assisted fabrication, visual capture, and digital sound synthesis to cast kinetic motion as control points for audio effects. We hope this practice inspires musicians and instrument designers to see physical kinetic mechanisms as opportunities for motion capture and sound mapping where the modes of sound control tend towards natural resonances of the physical system. When mapped to sound synthesis, these low frequency resonances become tendencies and constraints in the performance system. Therefore, the instrument may be deployed to diffuse aggregate textures of sound, or frequency domain effects as explored here,rather than granular control of local sound events.

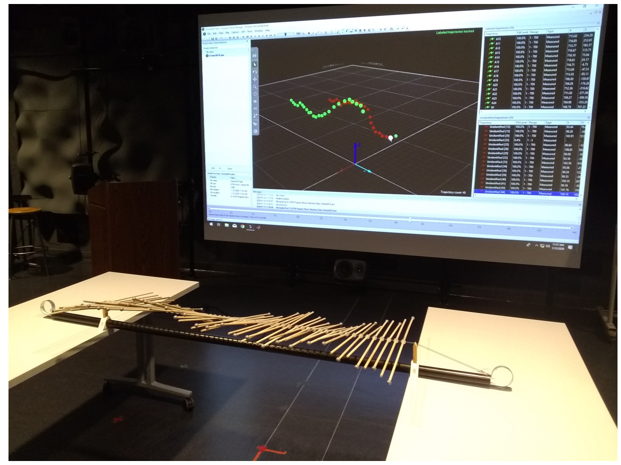

Figure 4: Shive machine with markers on the tips of the rods being tracked by the MoCap system. Screen in the back displays the QTM Software showing the tracking of the markers in 3D space.

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