CYMATIC SYNTHESIS OF A SERIES OF BELLS

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ABSTRACT

Frequency analysis and additive synthesis are the conventional way to reproduce sounds in signal processing. However, digital fabrication provides an alternative way to reproduce sounds by geometrical reproduction of acoustics. This paper proposes cymatic synthesis by geometrical reproduction as an alternative to signal processing as a way to design sounds. IN the other direction, cymatic synthesis can also be used to design geometric shapes from sounds. The potential of cymatic synthesis was explored through an experiment to produce a recursive series of bells, where the geometry of each bell is constructed from the spectral profile of the previous bell in the series. The knowledge gained from these experiments is captured in a process model with modular stages of SHAPE, SOUND, XFORM and PROFILE. Based on the results of the first experiment, we have designed further XFORM mappings that are more directly cymatic than the spectral profile. The substitution of alternative XFORM mappings demonstrates the modularity and generality of the process diagram. These mappings also demonstrate the creative and generative potential of cymatic synthesis.

1. INTRODUCTION

The Fourier analysis of sound into frequency components, and the resynthesis of the sound from sine tones, is a common process in signal processing. A similar process has recently become common in digital fabrication, where an object is scanned in 3D and then remeshed to 3D print a reproduction. Initially, digital reproductions could only be printed in plastic, but the range of materials now includes ceramics, glass, and metals such as stainless steel, bronze, and brass. This diversification of materials also brings a diversification of acoustical properties, and the resonance of metal underpins the invention of early musical instruments such as gongs, bells and singing bowls. The size and shape of these acoustic objects affect the pitch, timbre, duration of ringing, loudness, and other aspects of the way it sounds. The digital fabrication of an acoustic object is also a way to reproduce the sound that it makes. In cymatic experiments the effect of the shape of an object on is acoustical resonance is made visible, by for example, patterns of grains sprinkled on the surface of a metal plate attached to a speaker, or ripples on the surface of water in a bowl placed on the speaker. These cymatic experiments raise the question of whether the sound recording of an object could contain enough information to reconstruct the geometry of the object? Or would it produce a class of objects that all have the same acoustics? If the sound of an object is used to construct another object, does that object produce a different sound or the same sound as the original object? Speculating further, what would happen if we then recorded the sound from the new object and fabricated yet another object from that sound? This recursive process would generate an interleaved series of shapes and sounds, as shown in Figure. 1. The question then becomes – where will it end?

Figure 1. A recursive series of shapes and sounds

In this paper we propose that "cymatic synthesis" by the geometrical reproduction of a sound through digital fabrication can be an alternative to frequency analysis and additive synthesis. The questions raised by cymatic synthesis could, perhaps, be answered by a computational simulation using finite mesh modelling. However, the simulation of complex objects is computationally demanding, and involves many simplifications and assumptions. In this paper we explore digital fabrication as an alternative method for understanding and designing the acoustics of complex 3D objects.

2. BACKGROUND

In the 17th Century, Galileo Galilei noticed strange marks appeared on a metal plate that he was chiselling whenever the plate produced a harmonic whistling sound. A century later Ernst Chiadni described the vibration patterns produced by sprinkling sand on a metal plate and bowing it with a violin bow. In the 1960's Hans Jenny coined the word cymatics to describe his study of the modal vibrations of sound waves in 2D plates [1] Today, cymatics is often used to teach acoustics in science classes, through simple experiments with corn-starch on a speaker as shown in Figure 2.

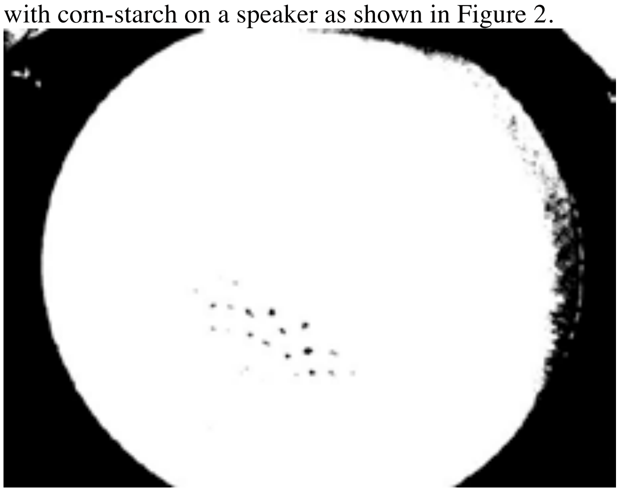

Figure 2. Cornstarch solution under the influence of sine wave vibration : Photo – Collin Cunningham

The cymatic transitions between regular patterns and chaotic forms have inspired many visual artists, such as Alexander Lauterwasser who published a book of photographs of light reflecting from the surface of water set in motion by sine waves and music [2]. The light levels from photographs of sound vibrations in water were height mapped to generate a sculptural object, titled 48Hz and shown in Figure 3, that can be purchased from the Shapeways.com digital fabrication community site [3].

Figure 3. 48Hz – digital fabrication of a cymatic form

A search for "sound" on the Shapeways site returns CAD models of flutes, pan-pipes and whistles that can be fabricated in plastic or metal. There is also a wind-chime that can be fabricated in glass or ceramic to produce tinkling sounds. These examples demonstrate the potential to use CAD tools and digital fabrication services to custom design acoustic forms and musical objects.

In the lead up to the new Millennium in 2000, Neale McLachlan proposed a project to construct 200 harmonically tuned bells for a public sculpture called the Federation Bells, shown in Figure 4. Traditionally bells are tuned by craftsmen who lathe the thickness profile of a cast bell. However the high cost offhand crafting led McLachlan to choose a mechanical process of pressing sheet metal, which is also very precise and consistent. Finite mesh simulations of bell shapes were used to identify the geometric factors that influence the acoustics and harmonics that included thickness profile, curvature, conical angle, circumference of the opening rim, thickness of the rim, and the overall width and height of the bell [4]. The curvature of the fixed thickness metal sheets was varied to produce the desired harmonic structure during fabrication.

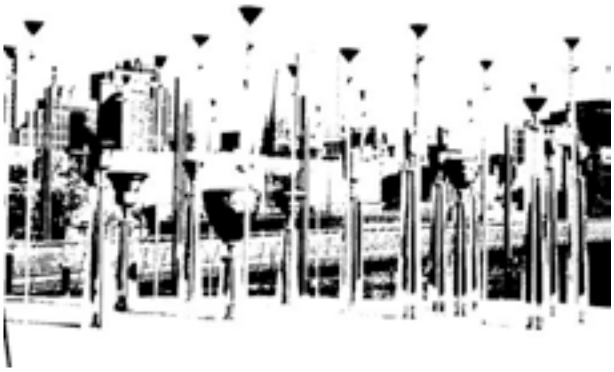

Figure 4. CAD designed Federation Bells.

Digitally designed bells have also been fabricated by 3D printing in stainless steel as part of an experiments in the Acoustic Sonification of digital datasets [5]. The bells were constructed from a dataset that measures the acuity of human spatial hearing in 3D, and fabricated by laser sintering to produce an irregular bell where the timbre and pitch of the ringing tone changes with the dataset that has been mapped onto the shape. These Sonification bells ring for 1-2 seconds, demonstrating that it is feasible to digitally fabricate sounding objects.

3. DIGITAL FABRICATION OF A BELL

Digital fabrication places constraints on size, thickness and level of detail, depending on the material. The Shapeways.com [6] service constrains stainless steel to a maximum bounding box of 1000x450x250mm, wall thickness of 3mm, and detail of 0.6mm. A simple bell shaped 3D mesh was constructed from graphic primitives using the Processing open source environment for programming 3D meshes [7]. An outer hemispherical shell with diameter 42mm and height 34mm was algorithmically constructed. This outer shell was then duplicated, scaled and translated to make an inner shell. The rims of the outer and inner shells were "stitched" together with polygons to make a watertight shape. A handle was added so the bell could be held without being damped. The digitally constructed bell, shown in Figure 5, was saved as a CAD file in STL format.

Figure 5. Graphic rendering of CAD mesh

File uploads to the Shapeways site are limited to 64MB and 1 million polygons. This may seem like a lot of polygons for a simple structure but the process has been set up to allow more complex structures. The high resolution mesh was reduced in size by merging close vertices in the Meshlab software for editing meshes [8].

The mesh was checked to be manifold and watertight with the Netfabb software for editing and repairing 3D meshes for additive manufacturing [9]. The CAD file was then uploaded to Shapeways, and fabricated in stainless steel with bronze colouring, to produce the prototype in Figure 6.

Figure 6. Digitally Fabricated Bell

When the bell was tapped with a metal rod it produced a tone that rings for approximately 1 second. The sound was recorded at 48kHz sampling rate with a Zoom H2 recorder in a damped room, and the recording is shown in Figure. 8. For the symmetrical bell shape, tapping anywhere on the rim has the same effect.

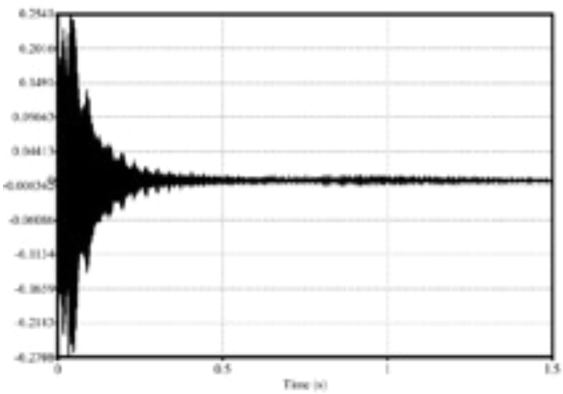

Figure 7. Waveform of Bell 0

The spectrogram of the ringing sound, in Figure 9, has partials at 2971, 7235, 13156, 20359 Hz. The first partials rings for ~ 1.2s, second ~0.75s, third ~0.5s and fourth ~0.2s. The temporal development of these partials produces the timbral "colour" of the bell. Although the partials are not harmonic, the bell produces a distinctly pitched tone.

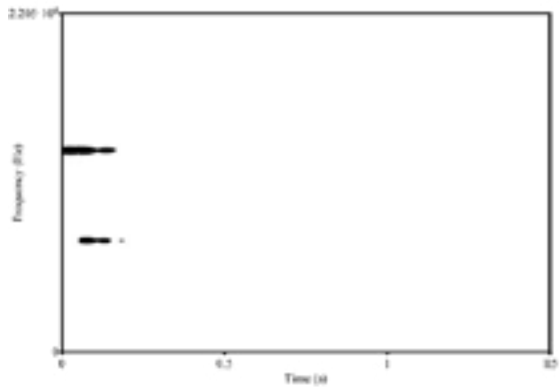

Figure 8. Spectrogram of Bell 0

The Long Term Average Spectrum (LTAS), shown in Figure. 10., is a 1D summary of the spectrogram. The LTAS shows the four major resonances that produce the timbre of this bell.

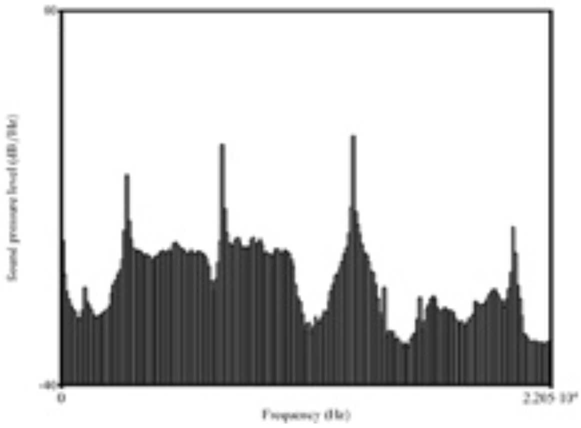

Figure 9. Long Term Average Spectrum (LTAS)

4. RECURSIVE PROCESS

This section presents an experiment to design a recursive series of bells where each bell is shaped by the sound of the previous bell in the series.

The stages of this recursive process are shown in Figure. 10. The process begins with the CAD file of the bell shape, BELL 0. The CAD file is fabricated as a physical object, SHAPE 0, which is the stainless steel prototype. The ringing of SHAPE 0 is generated by tapping the bell and recorded as SOUND 0. This sound is then transformed into PROFILE 1 by a process labelled XFORM. Then PROFILE 1 is added to BELL 0 and the new CAD file is fabricated as SHAPE 1, which is the next bell in the series. SOUND 1 is then recorded by tapping SHAPE 1, and XFORMed to create PROFILE 2, which is added to BELL 0 to create the second recursive bell. This process can be repeated ad. infinitum to produce a series of interleaved SHAPES and SOUNDS generated from each other.

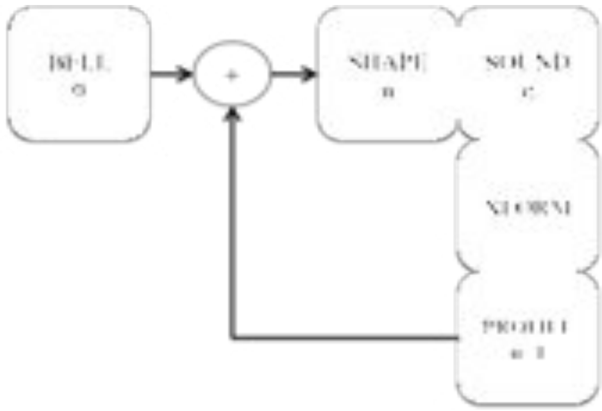

Figure 10. Recursive Fabrication Process

4.1. XFORM

The XFORM is a mapping from sound to a thickness profile that is added to the Bell 0 shape to alter the sound it makes.

The LTAS analysis of the prototype bell captures timbral features in a two dimensional format that can be used to algorithmically construct a thickness profile as a 3D mesh by rotation (or lathing) of the 2D profile. The LTAS has low and high frequency ends that could be mapped onto the bell shape in two different directions. The physical acoustics of vibration mean that larger objects produce lower frequency resonances, and smaller objects produce higher frequencies. This led to the decision to tonotopically map the low frequency end of the LTAS to the large circumference at the opening rim, and the high frequency end to the smaller circumferences at the top of the bell.

The first series of bells generated with this XFORM is shown in Figure 11. The first row shows the prototype bell, the waveform it produces, and the LTAS profile with 4 major partials.

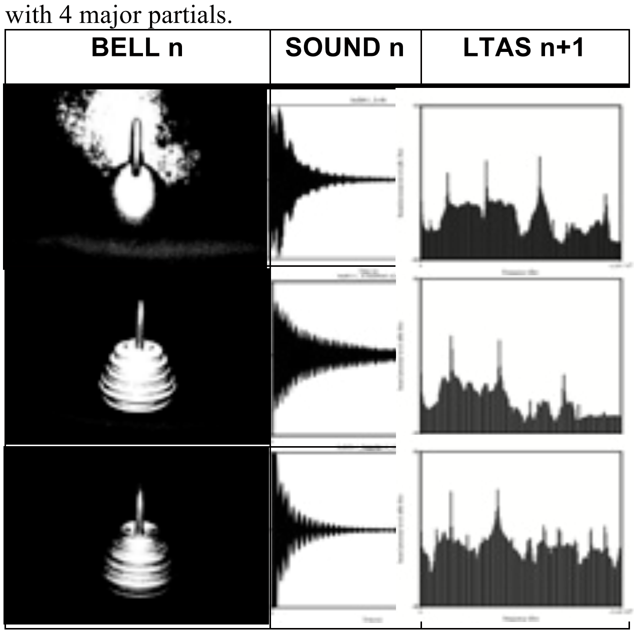

Figure 11. Recursive series of bells

The second row shows Bell 1, with thickness PROFILE 1 constructed by XFORM from the LTAS of Bell 0, and fabricated in stainless steel. The waveform rings for ~1.5s, and the LTAS shows 3 partials that produce a higher pitch, but lower timbral brightness. The third row shows Bell 2 shaped by the XFORM of LTAS 1, and constructed in stainless steel with gold colour. Bell 2 rings for 0.75s, but has only two main partials. The pitch is higher than Bell 0 and lower than Bell 1, and the timbre is brighter than either.

4.2. Profile Weighting

Bells 1 and 2 look and sound similar to each other. This led to the idea to increase the weighting of the shape profile. The weighting of the shape profile relative to the bell template can be adjusted in the mesh generating program. The weighting parameter T has been added to the process diagram in Figure. 13.

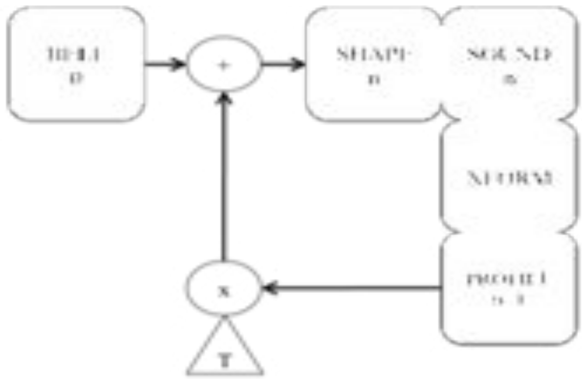

Figure 12. Process with profile weighting T

The next experiment tested the effect of varying parameter T on the sound of Bell 2. A new version Bell 2+ was fabricated with T double the previous level, doubling the geometric effect of the PROFILE. The results, in Figure 13, show an amplitude modulation in the ringing sound that is heard as a tremolo effect. There is also an increase in the frequency of the two main partials that make Bell 2+ a different timbre from Bell 2.

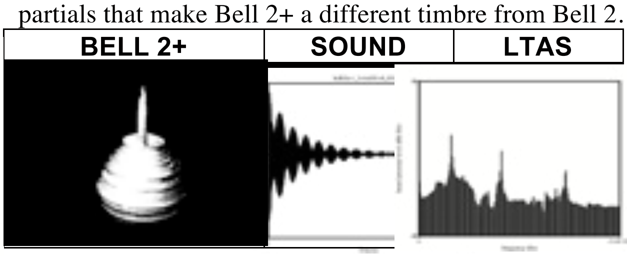

Figure 13. Bell 2+ with doubled parameter T

This suggests that increasing T may generate more variation in the series of shapes and sounds. The value of T was raised to 3x to generate Bell 3+ shown in Figure 14. This bell has flanges that are too thin to be fabricated in stainless steel. The unusual shape of the bell raises the question of whether more radically non-bell like transformations will ring. On the other hand, if this bell could be fabricated with a more high detail process in future the flanges may introduce interesting timbral effects, such as tremolos and vibratos, that are not heard in conventional bells.

Figure 14. CAD rendering of Bell 3+

5. DISCUSSION

The XFORM in these experiments is a mapping from spectral profile of the sound to shape profile of the bell. However there are many other ways to map sounds to shape. One of the reviewers of this paper submission commented that the time-domain waveform would be a closer approximation to the cymatic effect a standing wave would have on the modal response of a bell. This suggestion is explored in Figure 15, where the waveform envelope of the Bells 0,1,2 from Figure 11 are rotated by 90 degrees to give an impression of the bell-like shapes that could be produced this way.

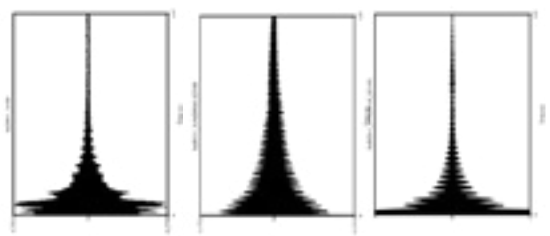

Figure 15. Waveforms of Bells 0,1,2 rotated 90 degrees to illustrate potential temporal profiles.

The XFORM mapping could combine both temporal and spectral features of the sound. For example the temporal envelope could modulate the circumference of a spiral rather than the linear mapping in Figure 15, to produce a shell-like conchoid, as shown in Figure 16.

Figure 16. Mathematical Conchoid

The LTAS profile could be superimposed onto the cross sections to produce an object shaped like a spider conch shell, as shown in Figure 17.

Figure 17. Spider Conch Shell

These more interesting sculptural and organic forms show the creative possibilities opened up by cymatic synthesis. The digital fabrication in metal with millimeter precision computer generated detail opens the door to explorations of acoustic forms that are more complicated than bells and other hand crafted instruments, with the potential to produce more complex and interesting timbres.

An even more literally cymatic XFORM could be based on the capture of the geometry of acoustic modes of the object rather than on the sounds the object produces. An experiment in this direction could begin with a circular metal plate, Gong 0, that is acoustically stimulated to produce a cymatic pattern that is digitally captured by camera or 3D scanner to produce a directly geometric, rather than acoustic, profile. This geometric profile would then be added to the geometry of Gong 0 to produce Gong 1.

6. CONCLUSION

This paper proposed cymatic synthesis as an alternative to signal processing as a way to analyse and reproduce sounds. This idea raised many interesting questions about geometrically based sound design and the effect fo shaping objects from sounds. These questions were explored by digitally fabricating a series of bells in stainless steel, where the shape of each bell was formed from the sound of the previous bell in the series. The process of converting sound to shape and back again was formalised in a process model with modular stages of SHAPE, SOUND, XFORM and PROFILE. A reflection on the first results of this process led to the identification of other possible XFORM mappings from sound to shape that are more directly cymatic than the spectral profile. The substitution of alternative XFORM mappings demonstrates the modularity and generality of the process diagram. These mappings also demonstrate the creative and generative potential of cymatic synthesis.

7. AKCNOWLEDGEMENTS

Thanks to the reviewer who suggested modelling a more directly cymatic shaping of the bell.

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