CREATING VISUAL IMAGES WITH SOUND AND VIBRATION

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There are many examples of visual images stemming from sound and vibration. Lissajous figures, named after the French mathematician Lissajous (d.1880), have long been a source of fascination and some have been used as commercial logos. Much attention has been given to Chladni figures, named after the father of modal analysis, Ernst Chladni (d. 1827). An extensive collection was published by Mary Waller (d. 1959) and Hans Jenny (d. 1972) photographed the response to high-frequency excitation of many different physical systems, solids, liquids and powders. Other examples of visual images include the response of thin metal plates to wide-band random vibration by which Chladni-type patterns may be generated. These essentially two-dimensional figures have been extended recently by Woodhouse to three dimensions. A three-dimensional sonogram has been used to cut decoration into new doors in a synagogue in Oxford.

Keywords: Chladni, Jenny, Lissajous, Waller, Woodhouse

1. Introduction

Recently, a single piece of old film, created a hundred years ago, became an iconic visual image.

The output of primitive seismometers recorded ground vibration caused by heavy guns firing in WW1. This was used as a means of locating the position of enemy guns by triangulation. One piece of this sound-ranging film recorded the few minutes when guns stopped firing at the agreed time on Armistice Day 1918. To mark the centenary of that event, London’s Imperial War Museum commissioned a sound reproduction company to recreate what the sound of those guns must have been like. The result went viral on the internet. The sound of guns booming, and then stopping, was accompanied by this simple, indistinct visual record, Fig.1.
That image was created accidentally. Many are created intentionally. The ICSV26 logo, fig. 2, based on Montreal’s Jacques Cartier bridge, embellished by a suitably-scaled vibration graphic, is an example. Others are Lissajous figures used as well-recognised logos for major establishments.

2. Lissajous figures

The French mathematician Lissajous [1] used the vibration of a double pendulum to create visual images. Two links of a double pendulum swing freely in vertical planes at right angles to each other. A writing instrument attached to the free end of the lower pendulum traces its position as it moves over a horizontal surface. These figures can now be generated easily by computer. An infinite number of variations are possible dependent on the length of the links, their relative amplitude and phase when released, and the amount of their damping. Four examples are given below. Figs. 3(b) and 4(b) show the logos using these stylised figures adopted by the Australian Broadcasting Corporation and MIT’s Lincoln Laboratory. Figs. 5 and 6 show the range of possibilities, from the fish in fig. 5 to the rectangular grid in fig. 6. There is at least one example of modern art created by swinging a stream of paint above a horizontal surface (Max Ernst, 1942) and there have been numerous papers on the double pendulum “art machine” (a term coined by Romer, [2]) and on the generation of chaotic responses (for example Shinbrot et al. 1991 [3]). However, in recent years, Chladni figures, and variants of them, have attracted more attention.

\[ \begin{align*}
\text{Fig. 3a} & \quad \text{AR}=1, \ FR=1/3, \ \phi=90^\circ \\
\text{Fig. 4a} & \quad \text{AR}=3/4, \ FR=4/3, \ \phi=0 \\
\text{Fig. 5} & \quad \text{AR}=5/2, \ FR=2/3, \ \phi=90^\circ \\
\text{Fig. 3b} & \quad \text{Australian Broadcasting Corporation logo} \\
\text{Fig. 4b} & \quad \text{MIT Lincoln Laboratory logo} \\
\text{Fig. 6} & \quad \text{AR}=1, \ FR=100/105, \ \phi=90^\circ
\end{align*} \]

**LEGEND:** AR=amplitude ratio, FR=frequency ratio, $\phi$=phase angle

3. Chladni figures

Chladni figures are created by observing the response of a dynamic system to (usually) harmonic excitation. Initial studies were of low-frequency modal patterns formed by a thin plate subjected to excitation by a violin bow (Chladni, 1802 [4]). Patterns were generated by the movement of grains of dry...
sand or similar material on a plate’s upper surface, when the agitated particles migrated to nodal areas. Later, more complex images were created by applying high-frequency excitation to many different objects (Waller, d 1959) and then by Jenny, Lauterwasser and others.

The method was extended to three-dimensional objects by Jenny (2001 [6]) who created elaborate patterns by exciting a liquid drop with sound, usually of constant frequency, sometimes with variable amplitude, recording the dynamic movement within the drop by Schlieren photography. The geometry and complexity of patterns depends on properties of the liquid, the droplet size, and the amplitude and frequency of its vibration. Jenny did not explore the scientific explanation for his patterns but his use of Schlieren photography normally detects refractive index changes caused by varying pressure and density. A typical scientific application of this photographic technique is the study of shock waves in supersonic flow. Jenny’s was a novel application and it is by no means obvious exactly what has been recorded, except that intricate patterns have been generated whose hallmark is symmetry. Excellent high-quality photographs are shown in Jenny’s book [6] and that of his student Lauterwasser [7].

The importance of symmetry in classical art has been analysed by Weyl (1952 [8]) and in much greater detail by Critchlow (Islamic Patterns, 1983 [9]) and others. Sharman found the geometry in some of Jenny’s images fitted precisely with that of the traditional Islamic zillij mosaic patterns she studied in the madrassa in Fez, Morocco. This is reported in Morris and Sharman [10], presented in 2005. A triptych by Lydia Sharman from that paper is reproduced below. It demonstrates how the 10-
fold symmetry of a zillij pattern matches that obtained by Jenny from the response of a water droplet subjected to high frequency excitation.

Fig. 12 Triptych by Lydia Sharman (2004) illustrating the relationship between a 10-fold medieval Moroccan zillij pattern (left) and a 10-fold sound pattern (middle) with the two superimposed (right) (from Morris & Sharman, [10])

### 4. Computer-generated Chladni figures

Chladni images are generated by the interaction of standing waves of different amplitude and direction. Rather than analysing the response of a complicated system experimentally, an alternative is to synthesise images by computing the interaction of different standing waves. This is a relatively simple modelling process, involving the combination of waves travelling in different directions. Some examples are shown below.
As noted by Morris and Sharman [10], many of the images in Jenny, Lauterwasser et al. show rotational symmetry. Fig. 16c shows Jenny’s image, fig.11, superimposed on the simulated result of 5 interacting waves, of the same amplitude and wavelength, travelling at 36 degrees to each other.

Additional computer generated patterns from standing waves are included below (Figs. 17a, b, c) to illustrate the range of visual images that can be created.

5. **Design guided by random process theory**

MIT’s Kresge Auditorium, was completed in 1955. Constructed as a thin-shell of reinforced concrete, supported only at three points, it was revolutionary in its day. Of particular interest in the context
of this paper is the interior design with some 1200 seats, each upholstered in one of several different strong colours. Random process theory was used to select the arrangement of colours so that no repeating pattern can be seen. This was done by generating a train of pseudo-random numbers using technology that is now part of random vibration theory.

The use of random numbers to design non-repeating patterns differs from the surprising experimental finding that, when some structures are excited by random excitation, patterns may emerge. This depends on the boundary conditions and the directions in which waves are reflected.

6. **Crandall figures**

In the 1970s, Crandall and his research students Witting and Lee [12] discovered that random vibratory excitation may, in some circumstances, generate patterns because spatial response is uneven and develops lanes of intensified response. The examples given are for uniform horizontal plate-like systems with straight-sided or circular edges. The application of broad-band random excitation from below at a point on the plate generates an uneven spatial response. As the number of vibratory modes increases (by increasing the bandwidth), surprisingly simple response patterns emerge.

The explanation is that, although very small, larger amplitude movement causes downwards acceleration greater than 1g and the grains of salt start to bounce and tend to drift towards regions of lower response. In general, plate response is greater near the point of excitation than away from it, so the salt would be expected to drift away from the point of excitation. Reflections of vibrational energy from the plate’s regular boundaries then lead to an uneven spread of energy with lanes of intensified response spreading out from the excitation point to form a regular pattern. In the order of 900 modes were excited in the experiments [11].

In the example shown below, fig. 20, excitation was applied at a single point midway along the short edge and one third of the way along the long edge, where the lanes of enhanced response intersect.

![Fig. 20 Salt grain experiment with random excitation (from Crandall [11])]![Fig. 21 Wave simulation of a similar case]![Fig. 22 Contours of simulation]

The positions of these strips of enhanced response depend on the nature of the boundary conditions, and enhancement does not occur when the boundaries are irregular. The way in which wave energy is reflected from the edges determines where enhanced response occurs.

By artificially simulating wave motion, using many waves of different wavelengths, similar behaviour can be simulated, figs. 21, 22. In these cases, interesting responses are generated by the interaction
of waves of many different frequencies. This is essentially different from the generation of a Chladni figure. Chladni images are produced by the vibratory, resonant response to excitation at a single frequency rather than the broadband response of a system to random vibration.

The computer modelling of how intensified lanes of vibrational response develop is complicated and does not appear to have been exploited by anyone yet.

7. Patterns from sound recordings

Sound recordings are essentially two-dimensional. Typically, sound pressure level is recorded on a time base. However, the short-time spectral analysis of a sound recording, using a moving average to follow the changing sound pressure, is an essential part of voice recognition and regeneration. It generates a three-dimensional record. As time advances along one axis, frequency is recorded along another axis, and amplitude along a third axis, to generate a three-dimensional spectrogram.

8. Woodhouse three-dimensional figures

The decorative use of three-dimensional profiles generated by time-frequency maps (variously called sonograms and spectrograms) has been exploited on at least two occasions by Woodhouse [12]. The first occasion was to make a retirement gift (Figs. 25a, b). The second occasion was to provide decorative carving for timber doors, using the sound recording of a person singing (Fig. 27).
In both cases, the three-dimensional surface of a sonogram was used. In the first case, a solid replica was generated by 3D-printing, and then gold plated. In the second case, the simplified profile of an inverted sonogram was used to cut into solid wooden doors.

9. Acknowledgements

We are grateful to Professor Jim Woodhouse who kindly allowed us to include his illustrations for decoration of the Oxford Synagogue. In a short paper, it is impossible to do justice to this topic. We apologise if we have omitted to mention other important examples of sound-generated images.

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