Frozen Waves

Exploring the Transformation between Sound and Object

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Abstract

In the project *Frozen Waves*, audio recordings are translated into physical objects and vice versa. Time is temporarily captured in space – space is released back into time. In doing so, the potential of visual music (Friedlander, 1998) and second order cybernetics (Von Foerster, 1975; Glanville, 2004) are used to develop a new experience that synthesizes sound and visual components into dynamic material form. In this “aesthetically potent environment” (Pask, 1969, p. 76), the research engages with digital ontology, sound visualization, sampling methods, and generative design practice. Similar works are Studio Realität (2008), Fischer (2010), Azzaro (2013), Paul (2012), and Ghassaei (2012).

The idea explored in this project is that objects are continuously changing processes in time. Through consecutive iterations of sound recordings, sound spectrum analysis, parametric 3D model creation, and materializing methods such as 3D printing, temporary physical representations of the acoustic world around the observer surface and are recomposed. These objects can, in turn, be immaterialized back to sounds that they were generated from, albeit in a form that is modified and shaped by their transformation process.

Emerging design work implies a semiotic polyvalence that is realized through a process of techno-transformative and generative methods. As such new patterns are created, comprising single parts that are restructured into rhythmic patterns. The individual samples do not act as quotes; instead they operate as generative material for systemic combination.

This project aims to act as a Front End creative inquiry (Sanders & Stappers, 2012) and its purpose is to trigger the audience to consider the potentials of sound as a form of unique, material user experience.

Keywords: sound, shape, transformation, transmodularity, circularity

Frozen Waves

Frozen Waves may be understood as a practice-led project (Scrivener, 2000) that caters for a process of a reflective/reflexive inquiry (Schön, 1983; Gray, 1996). The idea investigated in this project is that objects are continuously changing processes in time. Through continuous iterations of sound recordings, sound spectrum analysis, parametric 3D model creation (Figure 1), and materializing methods such as 3D printing, physical representations of the acoustic world around the observer arise and are recomposed (Figure 2). These objects can, in turn, be immaterialized back to the sounds that they were generated from, albeit in a form that is modified and shaped by their transformation process. This process leads to the development of a new experience that synthesizes sound and visual components into dynamic material form. Audio recordings are translated into physical objects and vice versa. The created objects in *Frozen Waves* can be considered prototypes for possible wearable solutions and forms of physical adornment. Time is temporarily captured in space; space is released back into time. In doing so, the potential of cocreation and Second Order Cybernetics are used to develop a new experience that synthesizes sound and visual components into dynamic material form.

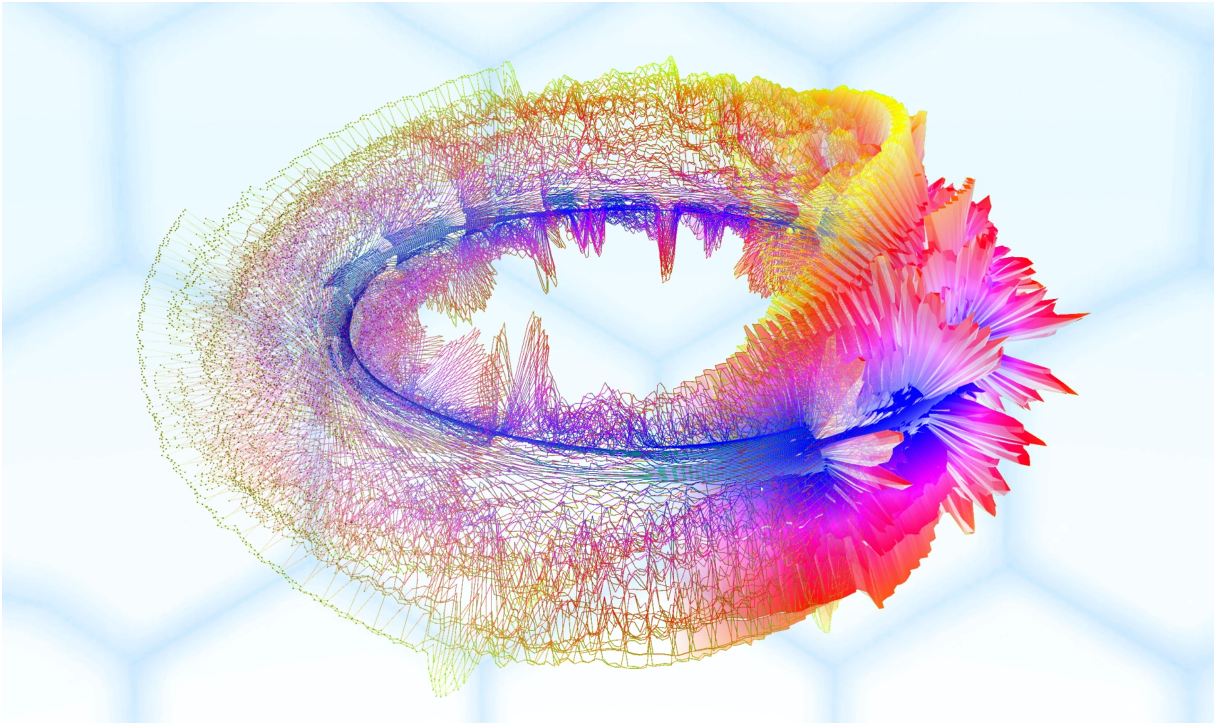

Figure 1. 3D representation of a 4 second sound recording.

Figure 2. 3D printed object of a 4 second sound recording.

Framing

Scrivener (2000) classifies design research into two sections: problem solving research projects and creative-production projects. Both forms of research employ the generation of artefacts, but they are significantly different in their essence and design development. Problem solving research projects, he suggests, are usually concerned with the development of new or improved artefacts. *Frozen Wave*s may be considered a creative-production project. Scrivener argues that in such a project the artefact may be more important than any “knowledge” represented in it. The knowledge he suggests “is a by-product of the process rather than its primary objective” (2000, p. 3). In this kind of research, the artefact may not be generated acknowledging a known problem and as such may not demonstrate a solution to a problem.

According to Schön (1983), a designer can only make sense of a situation that he distinguishes to be unique, because he observes it as part of an established repertoire of examples, understandings, images, and actions. It allows designers to generate creative work, by drawing on past experiences in their approach to novel and emerging challenges. Schön (1983) continues to describe the design thinking process as a reflective conversation between the designer and the situation. The emphasis is on cultivating new ideas, re-framings and appreciations emerging through practice. Rather it may be considered as a space that allows for transformations (Thomas & Carroll, 1979) where designers can exercise intuition and creativity. As such the problem need not be highly defined at the outset. By focusing on the present of making and future results, the designer explores the parameters of a situation and the resolutions, simultaneously. In *Frozen Waves* the creative and technological direction was based on a continuity of these reflective conversations between both designers and between the designers and their work.

It appears in diverse fields of design research where efforts are made to integrate innovation and creativity (Lockwood, 2010). Design thinking emphasizes the significant empathy for the context of a problem, creative approaches to generating insights and solutions, and concerns with the “fit” of solutions to the given context. At the core of its approach is a belief in knowing about the process and the methods that are used to ideate, and approach problems. Thus, it elevates “self-consciousness” and context to high levels of relevance.

Useful to the *Frozen Waves* project is the employment of a framework proposed by Frayling (1993) because “the end product is an artefact—where the thinking is, so to speak, embodied in the artefact, where the goal is not primarily communicable knowledge in the sense of verbal communication, but in the sense of visual or iconic or imagistic communication” (1993, p. 4). Frayling’s framework may be divided into three segments; research into design, research through design, and research for design:

- Research into design: The outcome of the investigation leads to a system for the synthesis of vision and sound, that requires research into sound systems and materiality
- Research through design: This engages with an understanding of the value of developmental enquiry as a valid research strategy. This trajectory involves a full synthesis of both analysis and application of understandings. This process leads to design iterations
- Research for design: Here, the designer/user, considers design related issues such as culturally defined epistemologies.

The majority of the *Frozen Waves* research took place within Frayling’s second construct, research through design. “The open and experimental iterations led to new found areas of design, not driven by a strong will to choose direction, yet directed by continuously paying attention to the moment” (Van Melle, 2013, p. 29). The work generated within *Frozen Waves* may be considered as a potential ingredient for initiating new processes from which new ingredients may surface. In this open framework, design iterations allow for experiments that are generated out of a response not to one stable question or the quest of an anchored “truth”, but to a collection of frequently changing ideas and outcomes. Frascara (1997) suggests that the purpose of methodologies is the creation of frames or paradigms within which design decisions take place. These provide guidelines to designers using a wide range of impacts

(Wallick, 2012, p. 20). This practice-led design research is not only about the generation of artefacts. It is also about the process of designing. Methodologically it intersects with the idea of cocreation (VanPatter, 2009; Sanders & Simons, 2009).

Cocreation

In a practice-led generative design research project like *Frozen Waves*, process is more than a chronology; it is intrinsic to a broader discussion of cocreation and "sensemaking" (VanPatter, 2007). The designer/researcher is concerned with mastering unframed challenges (Eikeland, 2006), and opening spaces for both questions and re-framings to develop. The approach to methodology is conceptually aligned with principles of design thinking. Design thinking describes the ideas and cognitive resources designers bring to a problem-solving process (Zimmerman, Forlizzi, & Evenson, 2007, p. 494). Generative design research is an emerging field which is best described as a form of participatory design research (Visser, Stappers, Van der Lugt, & Sanders, 2005). A generative design project is commonly concentrated at the very early stage of the design process, the so called pre-design phase, used to create contextual insights and explore design opportunities within the fuzzy front end of the design process. That is the aim of a generative design research that "leads up to the design opportunity decision" (Sanders & Stappers, 2008, 2014, p. 10).

"Contextmapping" has emerged as a term used to describe a design research methodology that seeks to explore the wider context around a design problem, with the aim to "inform and inspire design teams" (Kaptein, Weisscher, Terken, & Nelissen, 2009, p. 214) across the later stages of the design development process. *Frozen Waves* fits within this construct. Although the design team only consisted of two people, the project followed the five steps of study preparation, sensitizing participants to the topic at hand, conducting facilitated generative group sessions either in a face-to-face or online format, analyzing the material that was produced, and communicating the findings to the design team (Kaptein et al., 2009; Sanders & Stappers, 2012; Visser et al., 2005). According to Visser et al. (2005), contextmapping is a way to consider "all factors that influence the experience …" (p. 121). Kaptein et al. (2009) build on this idea and strengthen it by suggesting “the full understanding of questions about the experience: why, where, when, how, what, with whom, etc.” (p. 213). Here the experience is defined as anything that can be made into future design concepts such as products, services, or environments.

The last step of the contextmapping research process is significant to *Frozen Waves*, as it concerns the compilation of findings in such a way that they convey meaning, but still leave enough space for interpretation.

Cybernetics

Frozen Waves needed a theoretical framework in which dynamically controlled cyclic processes of generation and regeneration were evident. Cybernetics, or the Control and Communication in the Animal and the Machine, was coined in 1948 by the mathematician Norbert Wiener. The term emerged from a multidisciplinary inquiry into the flow of information around a system, and the way in which self control of the system is influenced through these information cycles (Beer, 1959). Second Order Cybernetics is the cybernetics of observing systems with an active role of the observer within the system (Von Foerster, 1975). In essence Cybernetics is about circularity (Glanville, 2004). It is a state of being: the observer observing what is happening in a specific system and at the same time acting on that system. Second Order Cybernetics and its concept of looping catered for the necessary background for the design researchers working inside a cyclic system.

The ideas behind *Frozen Waves* are far from linear and they seem to find common ground in Cybernetic systems in which control is always circular and realized through feedback mechanisms. Second Order Cybernetics was used as a way to understand the holistic character of these systems. It emphasized the dynamic connectedness of any part of the system to the dynamic totality of the whole system (Maturana, 1970). In such an approach to an enquiry Maturana (1970) suggests that the presence of the researcher is accepted rather than disguised. He continues with the idea that the observer is the person who guides the ship. He makes the comparison with a skipper, who acts both on practical know-how and intuition. In this regard, the skipper acts both as a scientist and an artist.

Cybernetician Gordon Pask distinguishes two orders of analysis. The first is characterized by the observer entering the system by conditioning the purpose of the system. In a second order stipulation, the observer infiltrates the system by conditioning his own purpose (Pask, 1969). Pask believes that linear control is a limited version of circular control and as such linear communication is a specially limited version of circular communication. Within the construct of Second Order Cybernetics, Pask (1971) describes aesthetically potent environments as "... environments designed to encourage or foster the type of interaction which is (by hypothesis) pleasurable" (p. 76). According to his research these environments must:

- Provide sufficient variety to provide novelty
- Provide forms that can be interpreted at various levels of abstraction
- Provide cues to guide learning
- Be responsive and engage the player in discourse.

In summary, Pask (1971) suggests that:

> ... in each case, the external aesthetically potent environment gives rise, bit by bit, to an internal representation and the reciprocal representation is internalised as a discourse between the internal representation and our immediate selves. (p. 89)

Related Work

"Frozen Waves" is bridging two currently separate bodies of work that are either purely related to the transformation of intangible audio signals into tangible 3D objects or purely related to the opposite "direction".

Studio Realität (2008) transforms selected music albums (e.g., "Jewels" by Einstürzende Neubauten or "Third" by PortisHead) into circular 3D printed shapes with different rings representing the individual tracks of the album and the height profile of each ring visualizing the dynamics of the track. While this process results in a tangible object that delivers an overall impression of the “feeling” of the album, it is a non-reversible, unidirectional process.

Fischer (2010) uses spectrum analysis to turn an audio track into a 3D-printed “landscape” that is exhibited with a scanning light sweeping over the object while playing back the original sound. Again, this concept is only unidirectional and the audible sound is not reconstructed from the physical object. Gilles Azzaro (2013) also employs a similar principle, but chooses a speech of Barak Obama and uses a laser line scanner to visualize the currently played section of the audio clip.

The reverse process of turning physical objects into sound is explored by Paul (2012), who uses a laser distance scanner to convert the silhouettes of objects into different pitches of a synthesizer that is accompanied by a beat track synchronized with the rotation of the object.

All of the above projects are purely unidirectional in that the transformation is not reversible. The project *3D Printed Record* by Ghassaei (2012) is capable of reconstructing sound from the 3D object, but is tied to the principle of a standard 12 inch record, not allowing for any flexibility in shape during the generation of the 3D artefact. Frozen Waves was designed around a transformation principle that allows for the reversal of the process, allowing for the reconstruction of the sound that 3D objects were originally generated from, albeit with a large range of freedom in the forming of the actual 3D objects.

Implementation

Principle

In order to transform sounds into geometrical shapes and back, it is necessary to utilize a transformation principle that can ideally be completely reversed without loss. One of those principles is the Fourier Transform, a mathematical way to transform a signal within a time domain, for example, sound waves, into a description of the signal within a frequency domain (Fourier, 1808).

The Fourier Transform is based on the idea that any signal shape can be constructed by adding up a variety of simple sine wave shapes with different amplitude and phase. Figure 3a demonstrates how two sine waves with 220Hz and 660Hz are mixed together to the resulting more complex waveform, shown in red.

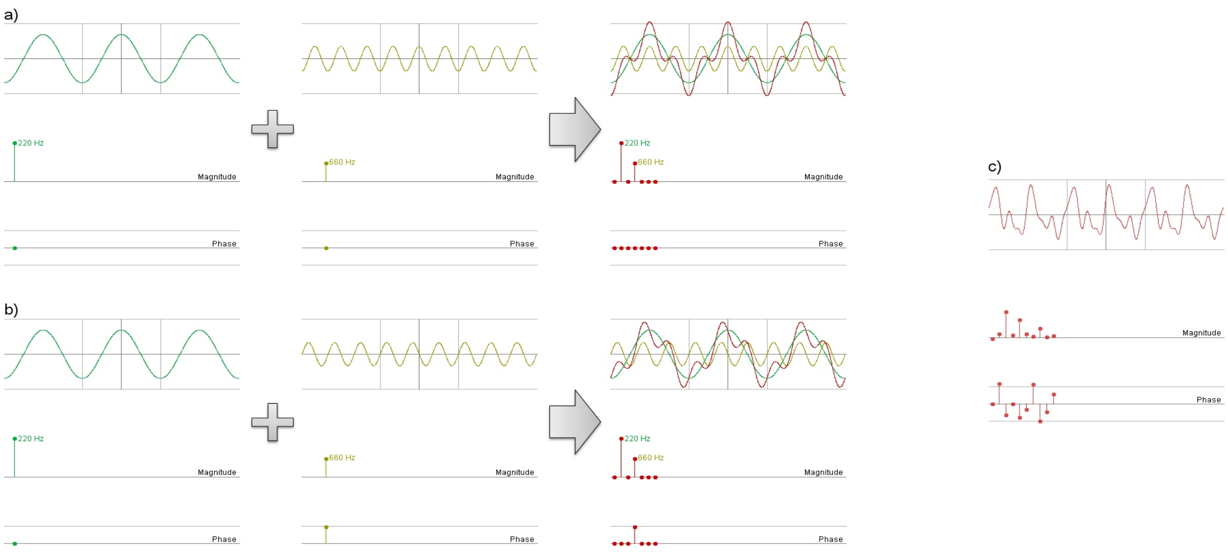

Figure 3. Principle of the Fourier Transform.

Figure 3b underlines the importance of the phase of each sine wave component that is added together, since by keeping the amplitudes of the two components identical, but varying the phase of the second component, the result looks completely different. Figure 3c demonstrates the frequency and phase components of a more complex wave that is constructed by 10 sine waves of different amplitudes and phases.

For *Frozen Waves*, we sampled the recorded sound snippets at a standard high-quality sampling rate of 44.100 Hz and broke the stream of audio information down into small blocks of 2048 samples each, which resulted in a block of 1024 frequency and phase parameters every 20ms, so roughly 50 times per second.

Numerical Transformation and Reconstruction

The basic idea of the transformation for *Frozen Waves* was to take the analyzed spectrum of the sound snippets and use the spectrum parameters for distorting and shaping the 3D object. Theoretically, extracting these parameters back out of the 3D shape (e.g., by scanning and analyzing the shape), it is possible to reconstruct the original sound from the shape.

However, during the analysis and transformation process, information is lost, in the form of rounding numerical values, averaging several values into a single one, omitting data, and only using the spectrum amplitude, but not the phase information. In order to analyze the effect of each of these types of information loss, we developed a program that would allow us to selectively degrade spectrum information of a sound clip and play it back reconstructed from the degraded information. Visualization of the signal and resulting spectrum would give visual clues to what happens to the original sound clip, and playback would provide the audible clue. Using this program, we were able to develop “a feeling” of how much you can degrade spectrum information before the reconstructed sound is not recognizable any more.

Figure 4a shows the spectrum of a 10 second music clip (left block, red indicating high intensity for a specific frequency), where the amplitude and phase of the original signal (top) is perfectly conserved. As expected, the waveform reconstructed from that information (bottom) is a perfect copy of the original, bearing no audible distortion or degradation.

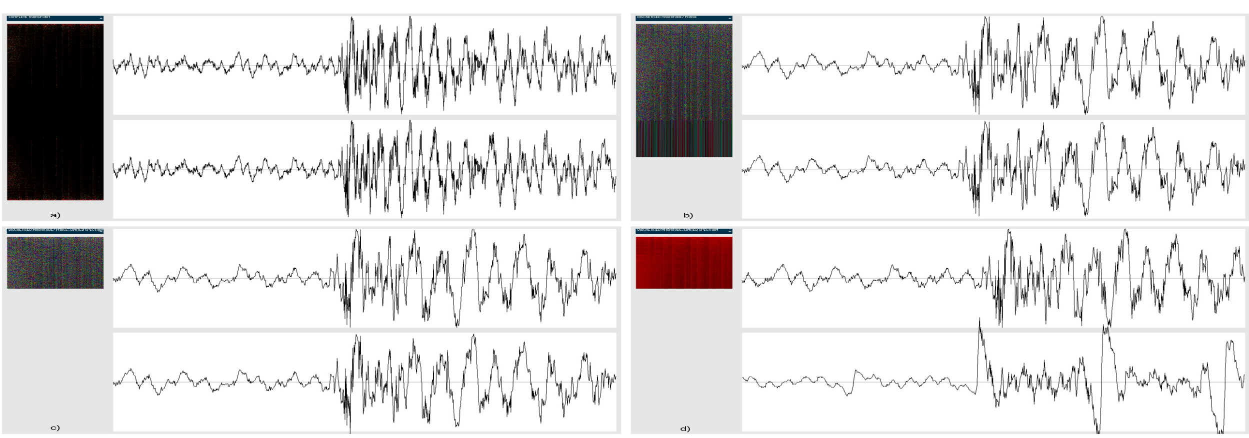

Figure 4. Reconstructions of sound from spectrum data with varying levels of information loss.

As a first step, we discretized the spectrum data. The results of the Fourier Transform are decimal numbers with several digits' numerical precision which we mapped into a range of integer numbers between 0 and 255 to be able to express them, e.g., as a pixel intensity or a pixel colour. As figure 4b shows, this discretization has only minor effects on the spectrum, which are neither visible nor audible. Note how the spectrum values (left) are now better seen as differently coloured pixels.

In a second step, we removed spectrum information for high frequencies by cutting away two thirds of the representing pixels. As expected, the reconstructed sound snippet sounds a bit dull, but not to the extent that would be expected by taking away more than 66% of the information. Figure 4c shows the reduced spectrum and the influence on the original sound, a barely noticeable reduction of fine details.
The most drastic change to the spectrum is the removal of all phase information. This loss of information results in spikes in the reconstructed signal in 20ms intervals, which are audible as a regular 50Hz hum-like impulse sound. In addition, the overall sound degrades to a hollow robot-like sound. The impact on the signal is also very clearly seen in Figure 4d. The impulses in the reconstructed signal also extend beyond the normal signal range and result in clipping artefacts when played back. This severe influence of signal quality stresses the fact that for a good reconstruction, amplitude and phase need to be preserved as much as possible (as discussed in the text related to figure 4).

Physical Transformation and Reconstruction

After the analysis of the numerical transformation and reconstruction, we extended the cycle to include physical matter. In a first experiment, we printed the spectrum image from Figure 4d, and reconstructed the sound through a webcam that captures a picture of that image. Figure 5 shows the setup of the printed spectrum (with its original image overlaid above it), the webcam, and the software turning the image back into the sound that it originated from.

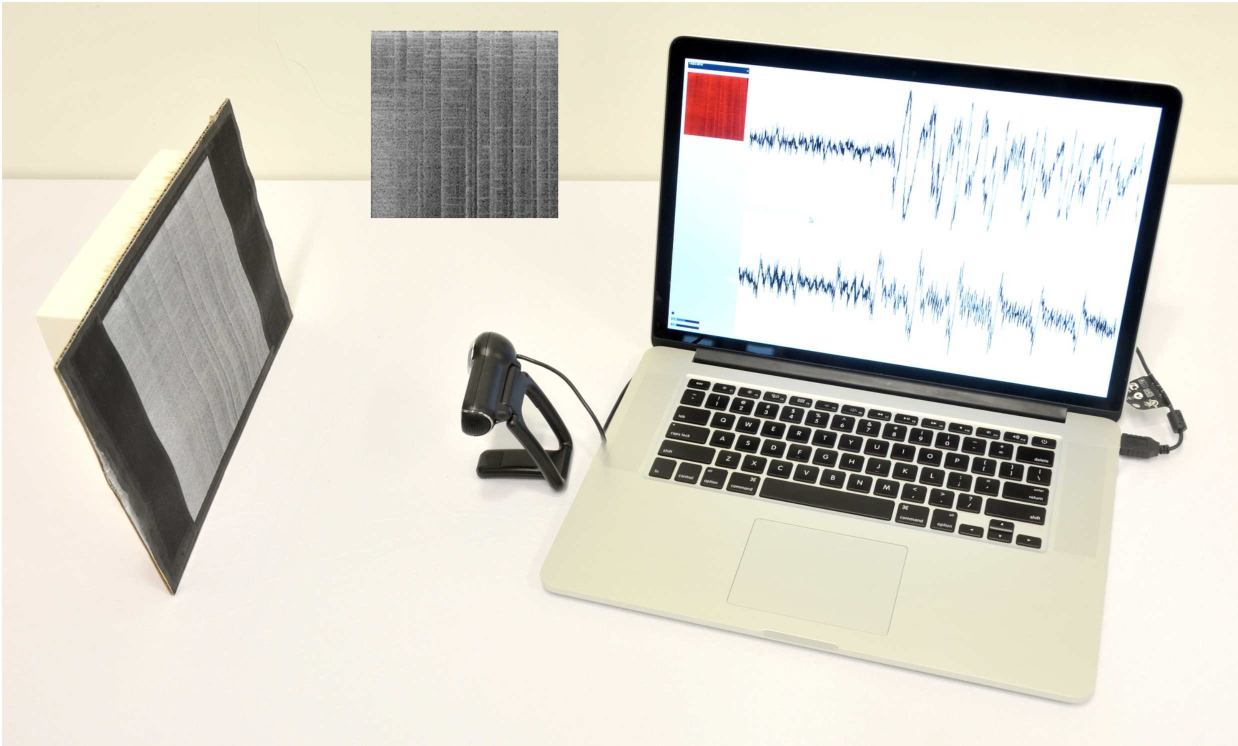

Figure 5. Reconstruction of sound from a spectrum image captured by a webcam.

We found that the spectrum as captured by the webcam is very sensitive to brightness differences. We had to add a contrast/brightness compensation into the software in order to avoid reconstructed sounds that were too quiet or too distorted. For a future application, it would be helpful to add pure black and white pixels or a grey scale to the picture that the camera and the underlying software can use to automatically adjust these parameters. Interestingly, turning the picture upside down resulted in a reconstruction of a sound very similar to a record being played backwards (although the frequencies were all reversed as well).

For our final experiment, we transformed the spectrum image into a 3D print where the height of a peak would indicate the spectrum amplitude. To convert the 3D object back into a spectrum image, we used the depth camera of the Kinect. Figure 6 shows the set up, including the wireframe model of the spectrum image that was used to create the 3D printed object.

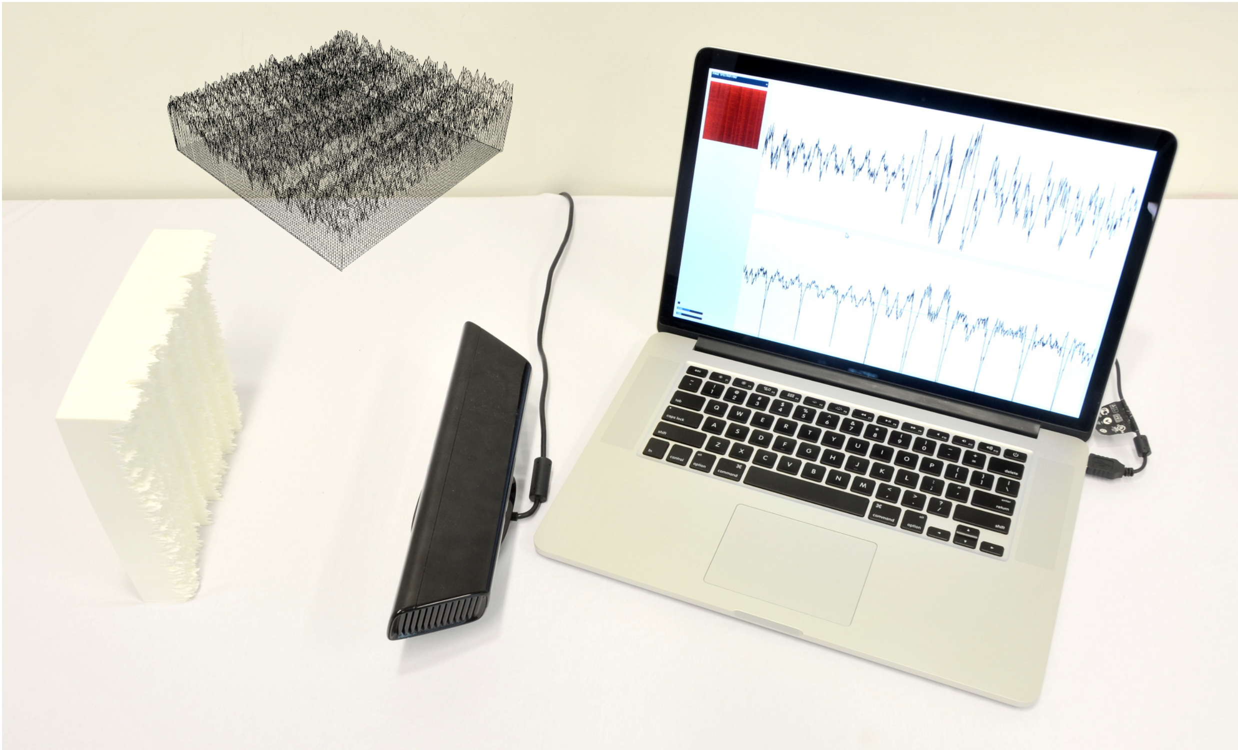

Figure 6. Reconstruction of sound from a 3D scanned object.

In addition to the problems we had encountered so far with the webcam, the low depth resolution of the Kinect added another loss of information and noise. After all, it is designed to track the movement of people within a room set up, but not to measure the precise 3D coordinates of spikes on an object very close to its lens. However, despite all the distortions and information loss, it was possible to still perceive some characteristics of the original sound clip, e.g., rhythm and general loudness.

With increasing complexity of the 3D transformation process, as applied for the shapes in Figures 1 and 2, the requirements for the accuracy of the scanning process and the complexity of the inverse transformation for the reconstruction of the sound will increase. However, our experiments have shown that sound is surprisingly “robust” against the distortions and losses that invariably will occur during the transformation and re-transformation process.

Conclusion

By implementing the Second Order Cybernetics paradigm the designer no longer operates as a discrete agent who moves the design in a linear direction from a set starting point. Linearity is an arguably limited way of understanding our world. Tapscott and Williams (2006) and Jenkins (2006) both suggest that polar binaries, single problems, and linear approaches are incomplete for handling current paradigm shifts. VanPatter (2007) argues that ‘‘sensemaking” is the driving force behind contemporary design. As designers find themselves increasingly becoming agents for “social transformation” (VanPatter, 2009), new creative inquiries and new levels of team-based creative problem solving become evident. Designers nowadays are faced with applying more than craft-focused solutions. Their outbound and inbound skill set (VanPatter, 2007) has become a much stronger intrinsically part of the solution. Thomassen (2010) notes that understanding and adapting to complex situations, creating and envisioning alternatives, and the ability to create quantities of ideas and concepts have become the main ingredients of design. The role of contextmapping in this design process could be seen as a way to establish what will most likely not be included in a final concept. It concerns setting a starting point, instead of an outcome (Visser et al., 2005).

From a practical point of view, we learned that for a good reconstruction of the sound from the physical domain, it is necessary to include and preserve the spectrum amplitudes as well as the phase, for example, by encoding amplitude as size and phase as colour. Also, the reconstruction process needs to be aided by including information that can help to reconstruct the absolute amplitude and phase values instead of just relative values. This could be achieved by using calibration patches with absolute black/white pixels or a grey scale, or, in the case of 3D models, sections of the model that represent the maximum and minimum values in 3D space. This project’s purpose is to trigger an audience to consider the potentials of sound and shape as forms of unique, material user experience. The concept to isolate and make lost information audible and visual opens new possibilities for future exploration. Investigations will be conducted regarding the implementation of our knowledge into fabric design, combining it with the

Shima Seiki seamless knitwear system to open novel critical approaches to an understanding of design, technology, and user experience. Through studying these ideas as practice-led researchers we believe new combinations and directions can surface.

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