A Malleable Interface for Sonic Exploration

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ABSTRACT

Input devices for controlling music software can benefit from exploiting the use of perceptual-motor skill in interaction. The project described here is a new musical controller, designed with the aim of enabling intuitive and nuanced interaction through direct physical manipulation of malleable material.

The controller is made from conductive foam. This foam changes electrical resistance when deformed; the controller works by measuring resistance at multiple points in a single piece of foam in order to track its shape. These measurements are complex and interdependent so an echo state network, a form of recurrent neural network, is employed to translate the sensor readings into usable control data.

A cube shaped controller was built and evaluated in the context of the haptic exploration of sound synthesis parameter spaces. Eight participants experimented with the controller and were interviewed about their experiences. The controller achieves its aim of enabling intuitive interaction, but in terms of nuanced interaction, accuracy and repeatability were issues for some participants. It's not clear from the short evaluation study whether these issues would improve with practice, a longitudinal study that gives musicians time to practice and find the creative limitations of the controller would help to evaluate this fully.

The evaluation highlighted interesting issues concerning the high level nature of malleable control and different approaches to sonic exploration.

Keywords

Musical Controller, Reservoir Computing, Human Computer Interaction, Tangible User Interface, Evaluation

1. INTRODUCTION

This work explores the use of fine-grained hand motion and tangible user interfaces for the control of digital music tools. Djajadiningrat et. al. [?] observe that 'current interfaces do not do justice to our embodiment in the world'. Computer musicians can benefit from input devices that exploit the use of perceptual-motor skill, with the aim of providing expressive and fluid control that promotes rather than inhibits creative workflow.

The interface described here is an Arduino[1] based project, which aims to enable musical interaction through the direct manipulation of malleable material. Malleable interfaces are currently seeing commercial outings in the form of the SUMA[2] and Blobo[3] devices, both marketed as *squeezable* controllers. There has also been plenty of activity in the academic sphere. Schwesig et. al. [?] describe the concept of *Organic Interfaces*, sensitive analogue devices that acknowledge the subtleties of physical interaction; they illustrate their ideas with the hypothetical Gummi device, a deformable display that responds to physical manipulation by the user, arguing that subtle physical interaction with a real-world object such as this would lead to a suspension of disbelief, a quality perhaps also desirable in a musical controller. Moving to real-world examples, Reed [?] created a prototype digital clay, using embedded wireless sensors and computer vision to measure manipulation of the material. An example very relevant to this project is Smith et. al.'s [?, ?] work; they created several input devices using configurations of multiple conductive foam sensors for use as interfaces for 3D sculpting and camera control. Milczynski et. al. [?] created the *Elastable*, a device that employs computer vision to measure deformation of a rubber surface in order to explore and sonify high-dimensional data sets. Chang and Ishii [?] designed the ZStretch musical controller, a fabric device that measures deformation using resistive strain transducers sewn into lycra. Lastly, another musical example is Weinberg and Gan's [?] *Squeezables*. They embedded pressure sensors into several soft gel balls which were played together as a collaborative instrument. Their evaluation showed that the players found this style of interaction to be expressive.

The system described here uses a malleable foam sensor, tightly coupled with reservoir computing mapping techniques, to create a device that can measure subtle physical manipulations and map them to multi-dimensional control streams. It is used in this case for the haptic exploration [?] of sound synthesis parameter spaces. The overall design aim was to create a way of interacting with a sound space that is subtle, nuanced and also intuitive in the sense that the system should feel natural and easy to use after very little or no practice. A user study evaluates how well this was achieved.

2. ECHOFOAM

With the design aim of making an intuitive malleable controller, the ability to track subtle, detailed physical manipulations was a key objective, and the choice of sensors was

[1] `http://arduino.cc`
[2] `http://www.cambridgeconsultants.com/news_pr257.html`
[3] `http://www.bloboshop.com/`

the most important decision in achieving this. Inspired by Smith et. al's [?] controllers, conductive foam (also known as ESD foam) was chosen as the sensor material, however with a key difference; where they used multiple independent foam sensors, this project uses a single piece of foam as a continuous sensor, with multiple contacts measuring the state of deformation. In this way, both large and subtle changes in the shape of the sensor can be detected with a relatively simple electronic circuit design. The measurements from this kind of sensor are complex and interdependent, so the system is tightly coupled with echo state network mapping techniques to create usable control streams from the output. The resulting system was named *Echofoam*.

2.1 Sensor Construction

Conductive foam has a useful property for making a malleable sensor; its electrical resistance changes when deformed. To exploit these properties, a current can be applied to a piece of foam and the resistance measured at multiple points within it. When the foam is deformed, the resistance changes in the area of deformation and the readings change accordingly, giving a consistent and localised measurement of physical manipulation. If the resistance is monitored at a wide range of locations in the foam, each individual deformation of the foam as a whole will be identifiable by a consistent set of readings, and even small deformations will be detected.

The sensor is constructed using low density conductive foam. 32 swg enamelled copper wire, selected for its thinness and flexibility, is tied into the foam with the enamel scraped away at the ends to make electrical contacts. One wire is used as a live wire at 5 volts, while the rest of the wires measure resistance, running to voltage dividers on a breadboard, and then into eight-channel analog multiplexer chips (type 74HC4051) controlled by an Arduino board. A control program running on the Arduino scans the voltage from each wire with the multiplexers and sends them to a computer via USB at 115200 baud. In this configuration, 16 sensor wires were used (see figure **??**). The wires were tied into 8 foam squares which were glued together into a cube shape. The system runs at approximately 100Hz.

A key design decision concerned how to place the wires in the foam in order to give the most useful data readings. Measuring resistance at multiple points in a single piece of foam leads to a stream of interdependent measurements; tracking the value of a single point will not necessarily be valuable, whereas tracking the complete set of measurements will yield useful information about the position of the foam. With this in mind, the wires were placed at irregular points in the foam, such that as wide an area of the foam as possible was covered. Measuring the resistance at the chosen locations leads to a consistent signature for any particular deformation.

2.2 Mapping Techniques

Given the complexity of the values streaming from the sensor, an appropriate mapping technique was needed to extract useable control data. Rather than try to decipher this procedurally, a *black box* technique was chosen to deal with these complexities transparently. Echo State Networks (ESNs) provide a valuable set of features for solving this class of problem. ESNs are a form of recurrent neural network, belonging under the banner of *Reservior Computing techniques* [?, ?]. These networks consist of a set of inputs connected to a reservoir of interconnected nodes, which in turn connect to output nodes. Figure **??** shows a simplified example, in reality the reservoir would be much larger. All weights are assigned fixed, random values apart from the output weights. To train these networks the output weights are adjusted to exploit the dynamics of the reservoir and achieve the desired behaviour; because only these weights are adjusted, training the network becomes a linear problem that is fast to solve. ESNs can be trained to approximate the behaviour of arbitrary nonlinear dynamical systems, making them a valuable tool for processing temporal data streams; for example Holzmann [?] applies them to audio processing, using them for tube amplifier emulation and nonlinear audio prediction. In the context of processing sensor data, useful applications include sequence recognition and dimensionality reduction.

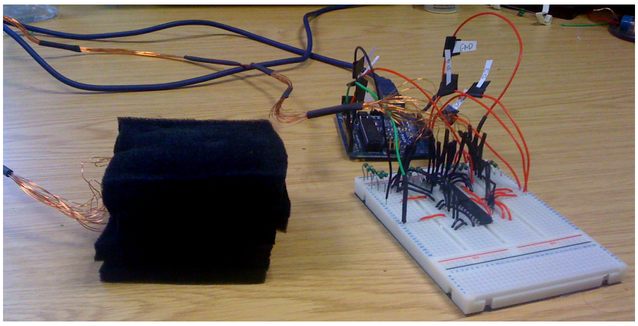

Figure 1: The Controller

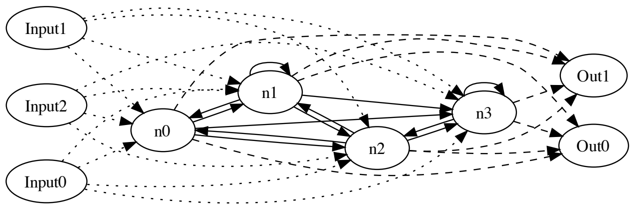

Figure 2: An Example ESN

2.3 Software

The ESN is implemented using Holzmann's *Aureservoir* C++ library [4]. A program running in the OpenFrameworks[5] environment controls the entire process, reading sensor data from the Arduino, mapping it through the ESN and sending the output streams to a sound engine running in SuperCollider[?] via Open Sound Control messages. This program also provides data stream visualisations and enables control of the training process. Figure **??** illustrates the overall process.

2.4 ESN Training

To train an ESN, a set of input data and corresponding output data needs to be created that defines how the trained network should behave. The control software facilitates the creation of training data, which is recorded in realtime; the foam is manipulated with one hand and computer number keys are held down with the other to set individual ESN outputs to zero or one. The complexity of training data required for good results is dependent on the behaviour desired of the system, and is best found through experimentation by choreographing varying sequences of inputs and corresponding outputs.

3. EVALUATION

[4]`http://aureservoir.sourceforge.net/`
[5]`http://openframeworks.cc/`

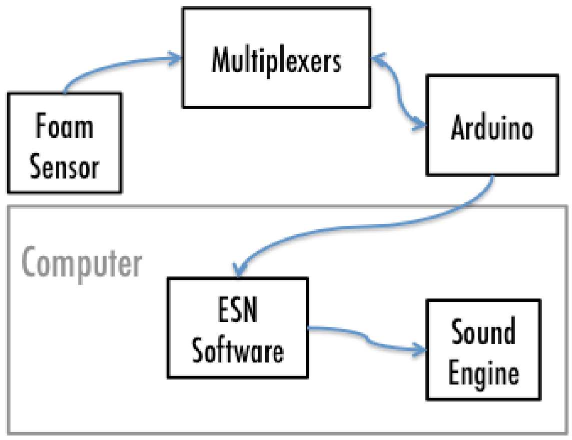

Figure 3: System Overview

Haptic exploration of sound synthesis parameter spaces was chosen as a context for the first evaluation of this system. After experimentation with ESN mappings, it was found that ESNs can be trained to output an arbitrary number of continuous data streams that change consistently with the position of the foam. A training set to achieve this behaviour is created by moving an area of the foam while holding a single output at a high value, and then repeating this for other areas and other outputs. Between moving these areas of the foam, the foam is left to settle while all outputs are kept at a low value. Figure **??** shows an example an ESN trained in this manner; the 16 input streams are converted to six output streams.

The nature of the training process means that the output of the ESN after training is somewhat arbitrary, but nevertheless consistent and potentially musically interesting. These output streams are used as control data for sound synthesis patches; as the player manipulates the foam the sound changes in accordance with its position, allowing the player to explore the sound space with touch, gesture and physical manipulation.

The evaluation comprised a set of interview sessions, lasting approximately thirty minutes each, where the participants experimented with the controller in various scenarios and were interviewed about their experience, the interviews being recorded as audio for later analysis. For all the scenarios, the foam controller was set up to be mapped to six continuous control streams through an ESN. The ESN was configured with 16 input nodes, 150 linear hidden nodes and 6 linear output nodes; the reservoir had a connectivity of 10% and a spectral radius of 0.8. It was trained with the pseudo-inverse algorithm, and the simulation ran with the *SimSquare* algorithm. Inputs to the ESN were mapped to between -10 and 10.

To provide a reference point, participants also tried controlling the same patches with six of the sliders on a Kenton Control Freak Studio Edition MIDI controller; this represented a conventional mode of control for sound synthesis.

3.1 Scenarios

The first scenario was the control of a phase modulation synthesis patch below (in SuperCollider code).

```
PMOsc.ar(p1, p2, p3, PMOsc.ar(p4,p5,p6))
```

Phase Modulation (PM) synthesis was chosen as it is commonly regarded as being highly unintuitive to program, an interesting challenge for an interface that attempts to provide intuitive control. This patch provided a large, varied and non-linear timbre space for the participants to explore.

The second scenario was a sound mixing task, where the six output streams controlled the volume of six looped variations of a vocal sample. These samples modulated together into a continuous soundscape that shifted subtly with the variation of amplitudes.

The final scenario was a variation on the first PM synthesis patch, where the range of control was constrained such that participants were working within a subset of the much larger parameter space. This gave finer control over the sound, providing a different experience from the first PM patch.

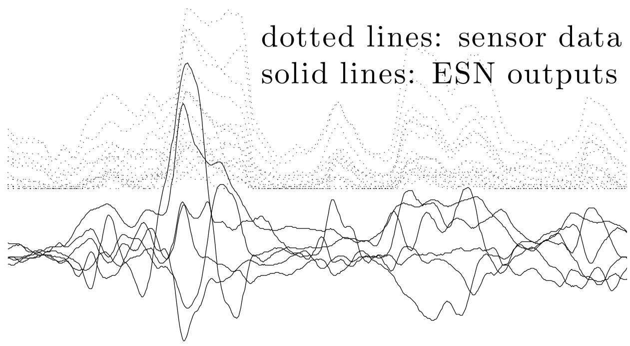

Figure 4: Echo State Network Mappings

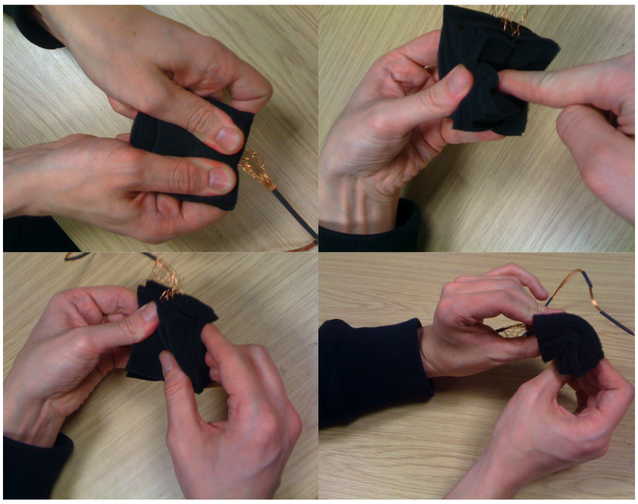

Figure 5: The Controller In Use

3.2 Participants

The participants were eight university students, all with experience in computer music. When asked to rate their skill in FM synthesis on a scale of one (none) to seven (expert), they responded with an average of 3.125, in a range from 1 to 6. They were also asked to list their total years of experience using separate computer music software packages, the sum of these years averaged 12 years, in a range from 5 to 19 years. Participants had an average of 5.86 years of musical training on consecutive instruments, ranging from 0 to 31 years. All participants were unpaid volunteers.

3.3 Method

In order to avoid influencing the participants' initial impressions of the controller, they were at first asked to begin exploring it without explanation of how it worked. After exploring scenarios one and two with both controllers, they were interviewed about their initial impressions, and the details about the workings of the system were then explained to them. They continued to try out the third scenario with both controllers and were interviewed again about their impressions of the system. Finally they completed a questionnaire on their preferences between the two devices in different situations, and their responses to this were used as talking points for a final interview.

3.4 Results

The eight interviews were transcribed and analysed using a grounded theory [?] approach. The participants' responses clustered around the following concepts:

Intuitiveness Participants generally perceived the foam as a natural and organic method of control *('I think [the foam] seems more organic, more natural, maybe intuitive, biological ... You weren't thinking about this region as much as this region, it was more about the tactile feel as opposed to looking')*. Some felt a more direct connection to the sound (*'It felt I was moving the music with my hands rather than moving controllers of it'*).

Learnability Participants perceived a range of learning curves, some finding the controller initially difficult to use (*'I couldn't get my head round when I was poking about with it, what that was doing'*), some finding it easier (*'you can just use it straight away, and practising with it gives a different sort of experience', 'manipulating sounds creatively, you can get some really interesting stuff out of that straight away, without prior planning'*). Most participants seemed to become more skilled with the foam over the course of the interview, although this may have been due to initial caution about breaking the sensor. Some thought it was instantly accessible (*'I think it would be really cool for people who don't really understand what's going on with MIDI to just play around with the music, and maybe kids'*) but would be difficult to master (*'I think you'd have to practice with it a long time to actually get the hang of it'*).

Physical Manipulation The freedom of movement with foam was something that some appreciated (*'The slider is two dimensional, foam is anywhere really, you can squeeze it from any angle, any pressure. This [slider] is just up and down', 'you were having a lot more control over sound because you could turn and twist'*). A wide range of motions were discussed, including squeezing, poking and twisting. Fingers, palms and hands were used to manipulate the foam, both single and dual handed. Some pressed the foam against the table, or squeezed one part of it while manipulating another.

High Dimensional Control It became clear in this sense that the foam was a markedly different approach to control from the sliders (*'I tried to establish the different parameters and really make them independent from each other, with foam it's very complex anyway because it's all entwined and there are no independent parameters, and all of a sudden it becomes a much more holistic abstract way of interacting', 'It's more related to human touch than it's related to the very limiting, one dimensional moves that you can make with the MIDI controller.'*). This was an issue for some (*'It's a lot more difficult to find independent dimensions'*) but not for others (*'I felt like I had the whole music in my hands', 'With the MIDI controller I felt like I had control over one individual parameter at any time but it was quite difficult to control the whole shape of the music'*).

Control Accuracy was an issue, in comparison to the sliders (*'You can get the levels of the sounds you like on the sliders quite easily, but it's a bit harder to get that exact sound that you're trying to achieve in foam', 'I find the foam at times a bit too course and a bit too crude'*).

Mapping Some participants felt the foam worked better with certain types of sounds (*'I can imagine using it one handed and it being a fun extra thing to use, for more effects based things','It actually felt like you could use it musically and have some control over it if you got used to it, especially on something where you were more controlling spectral stuff as opposed to pitch'*). Some enjoyed the correlation between motion and sound (*'[the foam] is interesting especially when you have these sounds where you squeeze something and you really feel that as you squeeze it the sound becomes tight and there is a correspondence between the actual physical activity of squeezing something and releasing it and also the sound became a bit tighter', 'It's very satisfying to express your relationship to what you hear ... if you hear something that's quite a hard sound you can also be hard about it in the way you touch the foam','It was kind of fun when you did properly manipulate the foam, you were crushing it and it did really go [makes crushing noise]'*).

Creativity One person felt that with the sliders, (*'you feel like you're operating a machine. I think [the foam] feels a bit more creative'*) while another felt that the precision of the sliders was more creative (*'You can control each little sound of the patch a bit more independently, I think it's a bit more creative in a sense'*). Some felt the foam was better for experimentation (*'It's about experimenting that you wouldn't make if you were looking for an exact sound. You're just stumbling across something', 'If it's more like doing weird stuff, then use the foam'*).

Visual References One participant requested to look at the data streams on screen as a reference, and commented on their experience (*'I think that what happens when you start to have a visual maybe that you become a bit more goal oriented, you are trying to move the sliders or move some sliders versus other sliders, which I didn't do before, it was purely just an internal experience', 'once you have a visual it becomes something else, because in a way your attention is divided'*). Another participant felt a visual reference would help with accuracy.

Repeatability There were mixed reactions about repeatability with the foam (*'[would you find it easy to go back to the same manipulation?] Yes because there's a body memory where your fingers kind of know where to go', 'It's easier to remember the way in which you twisted a piece of foam than it is to remember the positions of six different sliders, so it meant that I could, with a bit of practice, go back and forth between different settings', 'Sometimes I was trying to make the same thing* *happen twice but I couldn't always make that happen', 'There was one point where I had absolutely no idea how I'd made a sound and I didn't know how to get it back', 'You're not going to be able to necessarily remember that particular shape that you twisted it into to be able to use it again'*).

Exploration Participants were asked which interface they preferred for exploration; some preferred the MIDI sliders (*'I had more control over the different parameters so I could keep the rest constant and vary the others, whereas I didn't know how to control the parameters, I couldn't isolate one with the foam', 'You can turn everything one by one and learn what the components are and then you build up the sound enough'*), while others chose the foam (*'It was more fun just to explore around in the sound space and it meant that I could keep playing with it and find places where it sounded interesting', 'I guess as soon as you see six faders I was kind of methodically going through them thats really working out exactly whats going on, but that isnt necessarily exploring the soundspace in an interesting way, its a very sort of stepped, obvious way, its a lot more interesting to be doing it with the foam. Because you get results that maybe you wouldnt have done with just moving faders up', 'Its a much more intuitive approach because even though you get an idea where things are, theres so much mapping going on that you dont have a clear image in your head of where they lie so you explore it in an intuitive way and combine them in an intuitive way .. I can play with this a lot longer because it seems like there are more combinations I can make of bringing the sounds together than what I can do with the more structural MIDI controller'*).

Applications Several participants commented on the foam's potential as a collaborative tool. There were also comments about its potential as a performance tool, some negative (*'I'd like to have more control in performance'*), some positive(*'it fits more into the live set of music creation rather than sitting in a studio'*), and some from an audience perspective (*'It would visually be interesting', ' I think for performance, watching someone making motions that are in line with the human body in a sense that they are fluid is more aesthetically pleasing than seeing somebody moving a slider'*).

Fun Fun was a prominent theme in the responses about the foam (*'I had much less control ... over what was happening but that kind of made the foam thing more fun', 'It's just always a lot more fun when you're just using your hands in a natural way', 'This one's more fun to play with, more engaging without a doubt'*). When asked how important fun is in music, one participant replied *'oh loads, otherwise why would you do it?'*.

4. DISCUSSION

Having presented a summary of the results, before discussing them further it's also necessary to consider their validity in the context of the study that was performed. One shortcoming of this short interview form of evaluation is that there's a novelty factor that may influence the responses. Two participants also commented that they disliked the patches they were playing (*'I found it harder to understand how I was controlling it, maybe I just didn't like the sounds'*), this may also have affected their opinion of the controller. These problems would be ironed out in a longitudinal study, which would give participants time and space to practice with and find the creative limitations of the controller on their own terms. What these results do provide is a useful set of pointers from which a picture of the controller can be built; its strengths, weaknesses, and outlines of the themes and issues that concern and influence its design.

A notable strength of the system was its intuitive feel, participants describing it as feeling natural and organic, and giving them a direct tactile connection with the sound. The controller affords a freedom of motion in interaction, and a wide ranging vocabulary of manipulations were tried during the study. An interesting aspect of this is sound-motion correspondence, where the sound being generated is perceived as correlating with the physical manipulation of the controller, for example squeezing the foam causes the sound to become *compressed*. While a slider that can be moved up and down may only correlate with rising or falling elements of a sound, a malleable controller with many more degrees of freedom has potential for a wider range of correlations; mappings could be designed to deliberately exploit this feature.

An obvious weakness of the controller was accuracy. There are two factors in the design of the system contributing to this; firstly there is a small instability in the output of the ESN such that the output streams oscillate slightly. This is more noticeable in some patches than others. The nature of the foam itself is the other factor; when compressed and released there's a period of expansion where it returns to its original form, so there is inherent motion in the output. This issue of accuracy is closely tied in with the issue of repeatability, a topic on which participants gave a mixture of responses. The controller relies on a mixture of visual, tactile and proprioceptive senses for precise control, in this way it could be regarded as quite difficult to use accurately. It also relies on a vocabulary of gestures that are less commonly used for musical control; it's unclear from this study how practice might improve these issues, a longitudinal study would shed some light on this. The style of mappings that some participants stated a preference for follows on from these issues, they perceived the controller as being more useful for settings which required a lower degree of precision.

The high-level manner of control was an prominent issue. With the interdependent nature of the parameters, and the nature of malleable control where whole motions correspond to changes in sound, the underlying synthesis mechanism is obscured and the foam become an abstraction of this mechanism, the sound becoming embodied in the controller. Some participants saw this as a strength of the controller, it reduces the cognitive load of engaging with the underlying mechanism and lends toward a fluid style of interaction. Others found this awkward; they naturally approached the foam as they would the mixer, attempting to separate dimensions, however in an interface with a much larger freedom of control these dimensions are more numerous and less separable.

In terms of the creative potential of the controller, some felt that this was increased by its more imprecise nature, while others felt this detracted from it. (*'I personally feel that if I'm going to be creative I like to be a bit precise'*). This issue is closely tied in with the theme of the controller's intended use, as a mechanism for the exploration of sound spaces. Again the controller elicited a range of responses on this topic, participants who took a more intuitive, unpredictable approach to exploration tended towards expressing a more positive reaction to the controller than those who worked in more methodical manner. As Gelineck and Serafin [?] observe, musicians seem to like a tool that has 'a life of its own', so unpredictability and imprecision can have a useful place in the composition process.

5. CONCLUSIONS

A new malleable controller has been presented, which was designed with the aims of enabling nuanced and intuitive interaction with sound. To assess these aims, it was evaluated in the context of the haptic exploration of sound synthesis parameters spaces. The results show that the aim of designing an intuitive controller seems to have been achieved, but it's less clear from the results about the aim of nuanced interaction; accuracy and repeatability were an issue for some participants, and it's unclear whether these issues would improve with practice. A longitudinal study is needed to examine this, and also to complement the methodological shortcomings of the evaluation technique used here.

A common theme emerged from the analysis, of methodical and precise versus intuitive and freeform operation of the controller; participants whose style of musical interaction fit more into the latter category seemed to feel more comfortable with the device. This is congruous with the nature of a controller that is inherently slightly imprecise and allows a large degree of freedom of control. This theme of methodical versus intuitive shows parallels with Eaglestone et. al.'s [?] work on cognitive styles and the design of electroacoustic music software, a line of research that would be interesting to follow in the future.

This study highlights the potential of reservoir computing techniques for mapping musical interactions. Their temporal processing abilities coupled with the use of black box training methods could prove to be useful and interesting for musical interaction designers.

6. FUTURE WORK

There are a number of directions this research could take in the future. Firstly, variations on the sensor could be tested; different form factors and different conductive foams. Participants in the study were asked to suggest shapes for the foam, their answers included large balls, spheres with spikes and asymmetrical shapes which would help to map locations in the foam to sounds. There were several comments on the controller's potential as a collaborative tool, it would be intriguing to explore this as well.

There is still a huge space to explore with ESNs and interaction, their temporal processing abilities making them ideal for mapping controller data. Fundamental to the use of ESNs with interactive systems is the method of creating training data; this process is human controlled and so relies on the skill of the user to create high quality training data. This system allows the outputs to be set to either zero or one; a better system would allow varying output values to be recorded but would raise the skill requirement for training the system. Research into improving training methods would be valuable for the use of ESNs in this context.

Other materials (e.g. [?]) exhibit similar properties to conductive foam, of changing electrical resistance when deformed. The techniques outlined here could be applied to creating malleable controllers with these alternative materials, making an interesting comparison of tactile sensation.

7. ACKNOWLEDGMENTS

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