FerroSynth: A Ferromagnetic Music Interface

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ABSTRACT
We present a novel user interface device based around ferromagnetic sensing. The physical form of the interface can easily be reconfigured by simply adding and removing a variety of ferromagnetic objects to the device's sensing surface. This allows the user to change the physical form of the interface resulting in a variety of different interaction modes. When used in a musical context, the performer can leverage the physical reconfiguration of the device to affect the method of playing and ultimately the sound produced. We describe the implementation of the sensing system, along with a range of mapping techniques used to transform the sensor data into musical output, including both the direct synthesis of sound and also the generation of MIDI data for use with Ableton Live. We conclude with a discussion of future directions for the device.

Keywords
Ferromagnetic sensing, ferrofluid, reconfigurable user interface, wave terrain synthesis, MIDI controller.

1. INTRODUCTION
Reconfigurable musical controllers enable the musician to create a bespoke control interface that suits their performance style and the sound they wish to create, without the need for a complex set-up of multiple hardware devices. The Lemur [12] for example, enables combinations of virtual interface widgets to be assembled upon a multi-touch surface in a manner suited to the performer, whilst Pin & Play & Perform [25] allows a dynamic configuration of physical controls (e.g. knobs, sliders and buttons) to be freely positioned across a soft network substrate. In many cases however, reconfiguration does not extend beyond the layout or positioning of interface components. We propose the idea of a reconfigurable interface device that allows the physical form of the controller to be entirely altered rather than just re-arranged. We believe that this will result in a device where the method of playing and sound produced can be altered as a consequence of the chosen physical configuration.

We present FerroSynth: a "physically reconfigurable" music interface that is based upon ferromagnetic sensing. FerroSynth allows the user to interact by placing, moving and deforming a range of ferromagnetic objects above a horizontal interaction surface [9]. Such objects include, but are not limited to, ball bearings, iron filings, magnets and even smart materials such as ferrofluid and magnetorheological fluid. The user can quickly and easily reconfigure the physical form of the interface by placing combinations of these ferromagnetic objects upon the interaction surface, as shown in Figure 1.

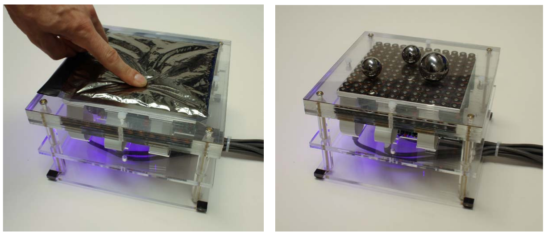

Figure 1. FerroSynth platform showing, (i) interaction with a ferrofluid bladder, and (ii) large ball bearing interface.

FerroSynth has three compelling qualities as an interface for music. Firstly the variation of the physical form of an interaction device will directly impact upon how it is "played". Certain objects will afford very different methods of manipulation, for example, a large ball bearing vs. a bladder of ferrofluid, and this will impact upon how the performer is able to interact with the device in order to create sound. Secondly, ferrous objects of different physical form produce varying sensor readings when placed on the device. A large ball-bearing will result in strong localized readings whereas ferrofluid will produce smaller and more dispersed readings. Finally, we believe that the interaction with physical objects will make the actions of the musician more performative. As the audience observes the variation in the physical form of the device throughout a performance, they will be able to better appreciate the effect upon the acoustic output that may have gone un-noticed if the performance were based purely around a laptop or touch-pad.

In this paper, we start with an overview of previous work in the field of reconfigurable musical interfaces, then lead on to a technical description of the device, present and discuss a range of techniques for mapping the sensor data to the creation of sound, and finally describe plans for future work.

2. RELATED WORK
The advent of computers in musical performance has allowed for a paradigm shift from single purpose acoustic instruments to flexible and multi-purpose interfaces and tools. Software sequencers [1], synthesizers [2], and patching environments [6] enable the performer to create an unbounded range of sounds from a single laptop computer. Many of these tools allow the performer to not only tailor the sound created but also the interface with which they interact.

As these flexible and reconfigurable software tools have emerged, new hardware devices have been developed to control them. These range from MIDI control surfaces to devices offering novel methods of control such as the touch-pad based Korg Kaoss-pad [14] or the Sonic Banana [22]. These devices

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have a fixed interface that is mapped to parameters of a software tool; however devices with an interface which can be reconfigured have also been developed. For example, interfaces based upon multi-touch surfaces such as the Lemur [12], and that developed by Davidson and Han [8], have a control interface which can be tailored by dragging and repositioning virtual representations of controls around an interactive surface.

Research into tangible user interfaces [11] has inspired the development of control devices that not only allow the user to configure the software mapping, but also the physical form of the controller. In systems such as the reacTable [13], Audiopad [19], Audio D-Touch [5] and BeatBearing [3], the user interacts with a selection of physical objects placed upon a horizontal surface; the spatial configuration of these objects is then used to manipulate a software synthesizer or sequencer. Additionally, devices such as VoodooIO [25] and Stekgrief [23] enable the user to position physical controls in a custom configuration using either a soft substrate or by arranging active bricks.

The idea of a reconfigurable physical interface has been extended by work such as Scrapple [15] to utilize the physical form of a tangible control object as a parameter. In Scrapple rubber scraps of different shapes and sizes are placed upon a table; their position, size and shape are determined and used to manipulate a stereographic score. Additionally, in Pebblebox and Crumblebag [16], physical objects of different qualities are moved and brushed together upon a foam covered surface; the interaction between these objects is tracked using a small microphone and used as a parameter to a granular synthesizer.

FerroSynth builds upon these previous reconfigurable music interfaces by presenting the ability to alter playing style, sound, and performance through the reconfiguration of ferrous objects above its sensing surface.

3. FERROSYNTH HARDWARE

Our device comprises a 2-D array of ferromagnetic sensor coils, each of which is 5mm high x 10mm in diameter and consists of 90 turns of 0.2mm enameled copper wire, wound around a small plastic former. In the centre of the former is a 5mm diameter neodymium permanent magnet, as shown in Figure 3.

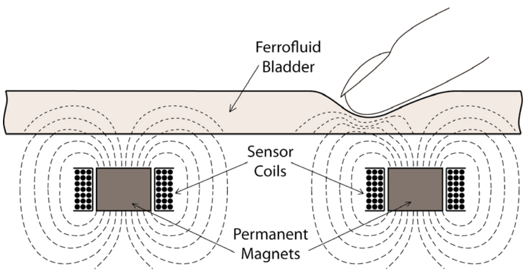

Figure 2. Cross section through sensor coils, showing disturbances to the magnetic field.

The operation of the sensor coils is based on a loosely coupled magnetic circuit, formed by the permanent magnet, the sensor coil and the ferromagnetic interface object. At rest, the magnetic flux through the coil is constant and hence no voltage is induced in the coil. However, user interaction with the interface object, as illustrated in Figure 2, causes disturbances in the magnetic flux which in turn induces a small voltage in the sensing coil.

Since the induced voltage in each coil is typically only a few millivolts, a dedicated amplification stage is provided for each coil. The current design supports 16 sensing coils, arranged to allow multiple boards to be tiled together; we have initially tiled 9 boards, which provides a total of 144 sensors spaced equally on a 12.5mm pitch covering an area of 150mm x 150mm.

Figure 3. (i) Individual sensor coil, (ii) 16 sensor coils mounted on the reverse of the analogue board, (iii) analogue sensing board, (iv) digital interface board.

The amplified sensor signals are then digitized (to 12-bit resolution) by a custom digital interface board which also transfers the digital data to a host computer via a USB interface. A more detailed description of the hardware design can be found in [9].

Custom software running on the host computer receives the sensor data from multiple interface boards and aggregates the values into a single array. To provide clean and reliable sensor data quiescent background values, sampled for each sensor, are subtracted from the raw data.

4. MAPPING THE SENSOR DATA

We have investigated a range of different approaches to mapping the sensor data obtained from FerroSynth to musical output. This has included both the synthesis of sound directly from the data and also the transformation of the data into a form that other third-party music/audio applications, such as Max/MSP [6] or Ableton Live [1], can use as input.

To support the generation of sound directly from FerroSynth, we have developed a DirectSound application which supports a circular output buffer into which we insert the processed FerroSynth data. Using this technique, we can construct time-varying data derived from the FerroSynth sensor and have it play out in real time. This underlying buffer architecture has allowed us to experiment with a variety of mapping techniques.

4.1 Wave Terrain Synthesis

In wave terrain synthesis [4], a time varying signal is generated by mapping a two-dimensional trajectory or orbit onto a three-dimensional surface or terrain. As a point moves in time along the trajectory, the z-value of the terrain translates to the amplitude of the output waveform. The terrain, which is a function of two variables, *wave(x, y),* can be derived from a variety of sources, such as tightly-constrained mathematical functions, geographic topography data, or a live video stream [7]. In the example given in Figure 4 (which is adapted from [20]), the wave terrain is derived from the function:

$$wave(x, y) = (x-y)\times(x-1)\times(x+1)\times(y-1)\times(y+1)$$

and the trajectory is given by:

$$x = 0.5\times\sin(8\pi t + \pi/5)$$

$$y = \sin(8\pi t)$$

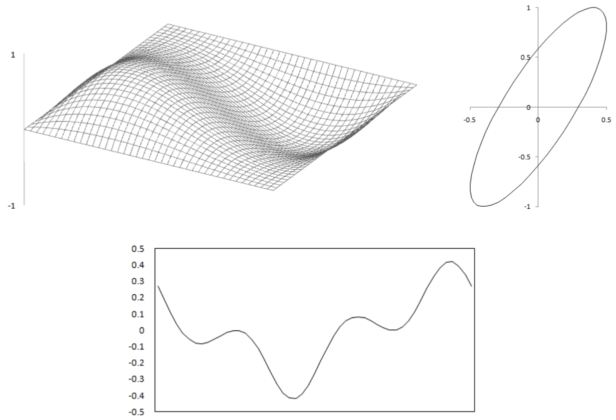

Figure 4. Wave terrain synthesis, (i) terrain, (ii) trajectory and (iii) time-varying output signal.

Using the concept of wave terrain synthesis, we have experimented with directly generating an output signal from the FerroSynth sensor data. In our first approach, we simply raster-scan [21] the 2-D sensor data into the circular output buffer of the DirectSound application. A variation of this technique is to scan the sensor data in a zigzag fashion [17], from top to bottom, then in reverse from bottom to top for one complete output cycle. This approach reduces problems of discontinuities in the output waveform and thus improves the quality of the final sound output.

Another approach, which is somewhat closer to that described above, is to map a periodic ellipse function onto the sensor data. In this case, a set of n output values are generated by sampling the sensor data on the path of the ellipse, as illustrated in Figure 5. It is worth noting that the pitch of the output sound is proportional to the scanning speed of the trajectory and is largely independent of the 'shape' of the terrain surface derived from the sensor data. The latter however, does significantly affect the timbre of the generated sound.

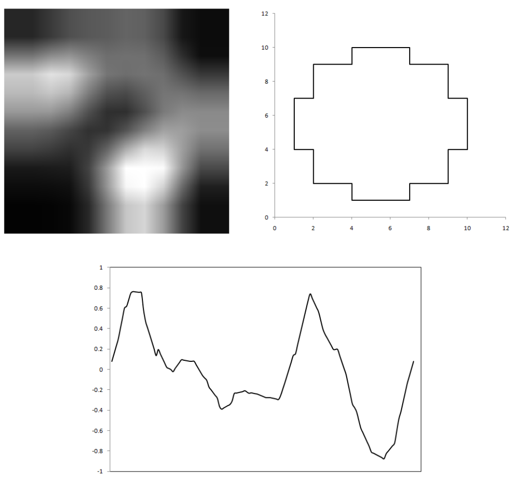

Figure 5. FerroSynth wave terrain synthesis, (i) smoothed FerroSynth data, (ii) elliptical trajectory and (iii) time-varying output signal.

A further variation of this approach is to incrementally offset the ellipse in either the x or y direction after each scan; wrapping is used in the case where the ellipse extends beyond the edge of the sensor data. This technique, which is an adaptation of scanned synthesis [24], has previously been reported as a way of enhancing the timbre qualities of the sound, since small cycle-to-cycle variations are introduced into the output.

Using these techniques, it is possible to create a wide range of acoustically interesting sounds, which can be further modified by altering the shape of the trajectory. For example, rather than an ellipse, we have also experimented with spirals. In this case, since the trajectory is not a closed path, we generate the output by first spiraling towards the centre and then back out towards the edge to avoid problems of discontinuities in the output waveform.

In each of the above techniques, we apply smoothing to both the 2-D sensor data and also the temporal output data to help improve the sound quality of the output. Finally, the level of sustain in the output signal is controlled by summing successive sensor values and then applying a decay factor.

4.2 2-D Wavetable Superposition

A relatively simple technique that we have also experimented with involves assigning a wavetable to each of the sensor locations, where each wavetable is filled with a different waveform. The output signal is then generated by the superposition of the wavetable data, with the amplitude of each wavetable being determined by the associated sensor value.

4.3 Scanned Superposition

An extension of the previous technique, which has also been used for image sonification [10], involves scanning the columns of sensor data and associated wavetable data, and generating the output again using superposition. In this case however, the output is generated sequentially for each column of data, with the column-to-column scanning frequency also affecting the pitch of the final output sound. The scanning continues until the final column of data has been processed, whereupon the scan returns to the first column and the process repeats.

4.4 MIDI Mapping

An alternative approach to synthesizing an output signal directly from the sensor data is to convert the data into MIDI notes and pass these to another application, such Ableton Live [1]. One advantage of this technique is that we can leverage the advanced synthesis capabilities of an existing application, rather than having to create this aspect of the process ourselves. In addition, this method creates a more generic input device that could be used to control a variety of other applications, for example the Jitter extension to Max/MSP [6], which would allow the real time manipulation of video data.

Adopting this approach, we have experimented with streaming the sensor data via a local network socket to a synthesis patch in Max/MSP. Additionally, using *Max for Live*[1], we are able to convert the FerroSynth data into MIDI notes which are then used to control synthesis instrument modules within Ableton Live.

5. DISCUSSION AND FUTURE WORK

The results achieved thus far have been extremely encouraging in terms of providing the musician with a device that offers a range of novel and interesting properties. The ability to quickly and easily change the physical form of the device allows for a wide range of different modes of interaction during a performance. For example, the ferrofluid bladder shown in Figure 1 provides a soft deformable interaction surface which

1 *Max for Live* is an Ableton Live extension that allows the integration of Max/MSP patches into Live.

typically generates multiple simultaneous sensor values. The ball bearings on the other hand clearly provide a hard physical interaction object that typically generates strong localized sensor output. Further to this, a magnet held and moved above the surface can be used to provide non-contact interaction, thus creating a device comparable to a Theremin.

Although we have focused on using the entire surface of the device for musical input, it is also be possible to subdivide the sensing surface and assign different areas to different functions. For example, physical controls analogous to traditional sliders and rotary knobs can be created using appropriately shaped objects with embedded ferrous material. These could then be configured to control various parameters of the synthesized output.

There are also many interesting directions for the future development of our device. We aim to investigate different approaches to mapping the sensor data to sound, such as granular synthesis or subtractive (filtered) synthesis. We are also planning to explore the use of active objects: In this case, one could imagine the user holding an electromagnet which is energized using a modulated signal. This would result in sensor data based not only on the position and movement of the object, but also on the modulation signal, which, if derived from the sensor data, would create a feedback loop offering yet more creative possibilities. Additionally, we hope to combine our sensing surface with a display in order visually augment the interface. This could be achieved using top-down projection or an LCD layer mounted on top of the sensing surface.

We hope to look at how the physical form of the sensing surface can be altered by placing the ferromagnetic sensing coils in different form factors. Such an approach would extend the level to which our device is “physically reconfigurable” especially if such a rearrangement of the sensing form could be completed dynamically by the user during a performance. One could imagine, for example, the sensor coils being plugged into a soft malleable substrate in a similar way to the Pin & Play & Perform system [25].

Finally, we foresee the potential for the combination of our sensing system with the magnetic actuation of ferrous objects, as seen for example in the Actuated Workbench [18]. The ability to excite and move physical objects above our sensing surface (using electromagnets) would allow for haptic feedback to be given to the user during a performance.

In addition to further technical development, we are also planning to more thoroughly evaluate the device by studying its use by a range of musicians. The initial feedback from users has been very positive, and we anticipate a more detailed evaluation will highlight qualities of the device that are compelling to musicians and guide its further development.

6. CONCLUSIONS

We have developed a novel reconfigurable interface device that offers musicians new and interesting possibilities for creating synthesized musical output. An overview of various mapping techniques is given that demonstrate how the device can be configured, along with a discussion of the various modes of interaction that can be achieved through the use of different physical interface objects. We conclude with a discussion of future possible directions including both the physical form of the device and also different mappings and styles of interaction.

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8. REFERENCES

[1] Ableton Live. http://www.ableton.com/live

[2] Absynth, Native Instruments. http://www.native-instruments.com

[3] Bennett, P. and O'Modhrain, S. The BeatBearing: a tangible rhythm sequencer. In *Proc. of NordiCHI 2008*.

[4] Bischoff, J., Gold, R., and Horton, J. A microcomputer-based network for live performance. *Computer Music Journal*, 1978, 2(3), 24–29.

[5] Costanza, E., Shelly, S. B., and Robinson, J. Introducing audio d-touch: A tangible user interfaces for music composition and performance. In *Proc. of DAFX 2003*.

[6] Cycling ’74 Max/MSP. http://www.cycling74.com

[7] Dannenberg, R. and Neuendorffer, T. Sound Synthesis from Real-Time Video Images. In *Proc. of ICMC 2003*.

[8] Davidson, P. L., and Han, J. Synthesis and control on large scale multi-touch sensing displays. In *Proc. of NIME 2006*, IRCAM — Centre Pompidou, 216-219.

[9] Hook, J., Taylor, S., Butler, A., Villar, N., and Izadi, S. A reconfigurable ferromagnetic input device. In *Proc of UIST 2009,* ACM, 51-54.

[10] Image to Sound Mapping. http://www.artificialvision.com/im2sound.htm

[11] Ishii, H., and Ullmer, B. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proc. of SIGCHI 1997*, ACM, 234-241.

[12] Jazz Mutant Lemur. http://www.jazzmutant.com

[13] Jordà, S., Geiger, G., Alonso, M., and Kaltenbrunner, M. The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces. *In Proc. of TEI 2007*, ACM, 15-17.

[14] Korg Kaoss-pad. http://www.korg.co.uk

[15] Levin, G. The Table is The Score: An Augmented-Reality Interface for Real-Time, Tangible, Spectrographic Performance. In *Proc. of ICMC 2006*.

[16] O'Modhrain, S., and Essel, G. PebbleBox and CrumbleBag: tactile interfaces for granular synthesis. In *Proc. of NIME 2004*, National University of Singapore, 74-79.

[17] Overholt, D. New Musical Mappings for the MATRIX Interface. In *Proc. of ICMC 2002*.

[18] Pangaro, G., Maynes-Aminzade, D., and Ishii, H. The actuated workbench: computer-controlled actuation in tabletop tangible interfaces. *ACM Trans. Graph*, 22, 3, 699-708.

[19] Patten, J., Recht, B., and Ishii, H. Audiopad: a tag-based interface for musical performance. In *Proc. of NIME 2002*, National University of Singapore, 1-6.

[20] Roads, C. *The Computer Music Tutorial*, The MIT Press 1996, 163-167.

[21] Seung, W., and Berger, J. Raster Scanning - A New Approach to Image Sonification Sound Visualization, Sound Analysis and Synthesis. In *Proc. of ICMC 2006*.

[22] Singer, E. Sonic banana: a novel bend-sensor-based MIDI controller. In *Proc. NIME 2004*, National University of Singapore, 220-221.

[23] Stekgreif. http://www.stekgreif.com

[24] Verplank, B., Mathews, M. and Shaw, R., Scanned Synthesis, In *Proc. of ICMC 2000*, 368-371.

[25] Villar, N., Lindsay, A. T., and Gellersen, H. Pin & Play & Perform: a rearrangeable interface for musical composition and performance. In *Proc. of NIME 2005*, National University of Singapore, 188-191.